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General File

February 4, 2000

Mr. George Robin
Groundwater Office of the Environmental Protection Agency Region IX
75 Hawthorne Street
San Francisco, California 94105

Dear Mr. Robin:

SUBJECT: Transmittal of reports

Per our telephone conversation earlier this week, enclosed are the following two technical reports:

> *Geology and Geohydrology of the Tulare Formation, 7G/18G Produced Water Disposal Area, South Flank NPR-1*, by Mr. Mark Milliken of the U.S. Department of Energy, December 1992

> *Geology of the Tupman Area, Naval Petroleum Reserves #1, Kern County, California*, by Mr. Mark Milliken of the U.S. Department of Energy, December 1993

Please call if you have any questions.

Sincerely,

Donna M. Thompson

Donna M. Thompson

Enclosures

cc: Mr. Dennis Champion, Elk Hills Power, LLC
Mr. Terry Schroepfer, Quad Knopf

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UNITED STATES DEPARTMENT OF ENERGY
NAVAL PETROLEUM RESERVES IN CALIFORNIA

TECHNICAL REPORT

GEOLOGY AND GEOHYDROLOGY OF THE TULARE FORMATION, 7G/18G PRODUCED WATER DISPOSAL AREA, SOUTH FLANK NPR-1

By
Mark Milliken
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12/8/92
Wayne Kauffman, Director, Engineering Division

12/8/92
Maurice Fishburn, Manager, Geology and Reservoir Management Branch

GEOLOGY AND GEOHYDROLOGY OF THE TULARE FORMATION, 7G/18G PRODUCED WATER DISPOSAL AREA, SOUTH FLANK NPR-1

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GEOLOGY AND GEOHYDROLOGY OF THE TULARE FORMATION, 7G/18G PRODUCED WATER DISPOSAL AREA, SOUTH FLANK NPR-1

Mark Milliken
December, 1992

I. Management Summary

This report is the result of an investigation into the relation between Tulare Formation geology and injected produced water (PW) movement in the section 7G/18G (T. 31 S., R. 23 E.) disposal well farm area. Rock units were described and bed attitudes measured from Tulare Formation outcrops in the study area. Geologic mapping is supported by review of several existing reports on Tulare Formation geology in the NPR-1 area.

Papers written prior to the 1980s were primarily concerned with oil bearing rocks, and the Tulare was lightly treated. Potential groundwater pollution from westside oil fields became an important issue with groundwater consultants in the 1980s, and the Tulare received more attention. Published reports generally observe upper and lower Tulare Formation distinctions and clay beds diagnostic as well log marker horizons. No two workers agree on Tulare Formation nomenclature. This report assigns the Corcoran clay to the alluvium, the Tulare clay to the upper part of the Tulare Formation, and the Amnicola clay to the lower part of the Tulare Formation.

Surface mapping, well log correlations, and water quality studies for this report show the Tulare and Amnicola clays to be important geohydrological barriers (aquicludes) to migration of disposed produced water across dipping beds in the 7G/18G area. These conclusions are supported by previously published groundwater reports in the vicinity of NPR-1. Groundwater elevation trends in the 7G/18G disposal area suggest lateral (along strike) movement of disposed waste water.

II. Conclusions and Recommendations

Conclusions. Geologic mapping of the Tulare Formation in the 7G/18G disposal well area suggests that alluvium in Buena Vista Valley, from which agriculture water production is obtained, is isolated from the Tulare Formation disposal wells by impermeable clays. No foreseeable danger of contamination is indicated. Given the vertical interval over which the water source wells are perforated, Tulare Formation porosity, and current rates of production, source well drainage radii will theoretically not reach the PW disposal wells for many decades, possibly beyond the 21st century. As there are no known offsite pressure sinks within the Tulare Formation, produced water is not expected to migrate off NPR-1 through the Tulare Formation.

Recommendations. The disposal of produced water into the Tulare Formation can continue unless a more economic use for the water, such as water flooding, can be found. Based on existing data, there is no reason to stop Tulare disposal out of environmental concerns. The cuurent program of monitoring source well water quality should continue. New disposal and source wells drilled on the southernmost flank of NPR-1 should provide more accurate log data. Drill cuttings should be described to gain more lithologic data on the Tulare Formation.

III. Introduction

Purpose and scope. Several public comments were received on the Draft Supplemental Environmental Impact Statement (DSEIS) requesting more technical work be added to support geologic and geohydrology discussions and conclusions. In response, this report investigates the relation between Tulare Formation geology and disposed PW movement in the 7G/18G PW disposal well farm area. Tulare Formation geology varies over relatively short distances in the field, and time did not allow comprehensive geologic mapping outside of the immediate study area. Sufficient levels mapping and correlations were made to fully support the conclusions of this paper.

Methodology. Rock units were described and bed attitudes measured from Tulare Formation outcrops in the study area. Apparent bed thicknesses (outcrop width) were corrected to true vertical thicknesses using known dips and trigonometry. Bed contacts were walked laterally and, with the aid of air photos, plotted on a topographic base as a geologic map. True vertical sections were correlated with well logs, measured dips on the surface, and structural cross sections were prepared. Stratigraphic nomenclature and correlations of the cross sections were checked for conformance with previously published data.

Location. The study area includes portions of 7G and 18G on the south flank of NPR-1 where the PW disposal well farm is located (figure 1). Data from wells in sections 13B, 14B (T. 31 S., R. 23 E.), and 20G were used for correlations.

Previous work. A number of geologic reports directly and indirectly related to Tulare Formation geology of NPR-1 have been written since the 1930s. Papers written prior to the 1980s were primarily concerned with pre-Tulare oil bearing rocks. In these older papers, the Tulare Formation was perceived as having little or no economic or scientific value, and so received little attention.

Among the first and still one of the best Tulare Formation papers directly related to NPR-1 is Woodring and others (1932). This paper has formed the foundation of most thinking over the years about Tulare Formation geology on NPR-1. Adkinson (1973) studied 1163 feet of Tulare Formation core from well 526-30R (T. 30 S., R. 23 E.). Maher and others (1975), like Woodring and others (1932) and Adkinson (1973), were primarily concerned with pre-Tulare oil-producing rocks.

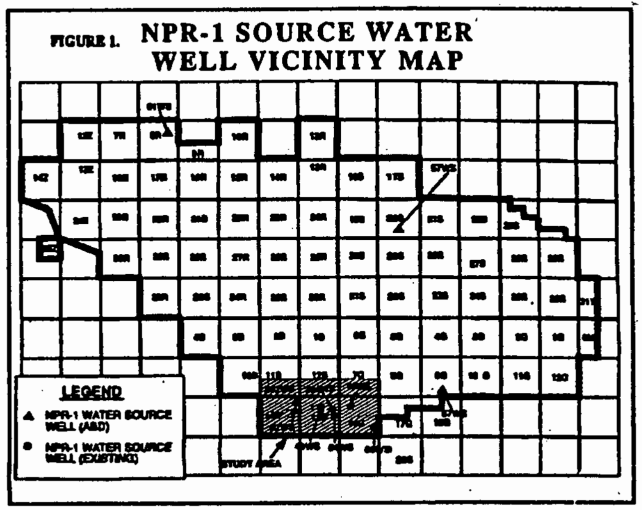

Figure 1. Study area includes water source wells and 7G/18G produced water disposal well farm.

Potential groundwater pollution from westside oil fields became an important issue in the 1980s. Since then, the Tulare Formation and overlying alluvium have assumed increased importance. Most of these reports have been done by consultants contracted byo industry or government. Overall, the reports provide beneficial data and are certainly useful. But these reports must naturally reflect the requirements of the customer, and so commonly fall short of pure scientific objectivity. Consequently, the reports tend to be contradictory among themselves. Errors in data interpretation and presentation are common. Investigators referencing these reports must carefully review the data and conclusions.

Bean and Logan (1983) studied westside hydrogeologic conditions under contract to the California State Water Resources Control Board. Rector (1983) looked at Southern San Joaquin Valley hydrologic conditions for Western Oil and Gas Association (WOGA). In 1988, Wilson Zublin Incorporated (WZI) prepared a report for Valley Waste Management, a consortium of westside oil companies cooperating to manage the disposal of produced water.

Golder Associates (1990) prepared a Groundwater Monitoring Plan for NPR-1. This report did not adequately address either Tulare Formation stratigraphy or structure in the 7G/18G PW disposal well area. Nicholson (1985), for the Unit Operator, presented a geologic study of the Tulare Formation in the 7G/18G area that did not adequately address stratigraphy.

IV. Stratigraphy of the Tulare Formation within the study area.

Tulare Formation nomenclature: a background. No two workers have ever completely agreed on how to name the various rock types of the Tulare Formation in the vicinity of NPR-1 (figure 2). The work of Woodring and others (1932) was limited to field mapping, as little or no

VARIOUS STRATIGRAPHIC NOMENCLATURE OF THE TULARE FORMATION AND OTHER LATE QUATERNARY ROCKS, ELK HILLS AREA

Figure 2.

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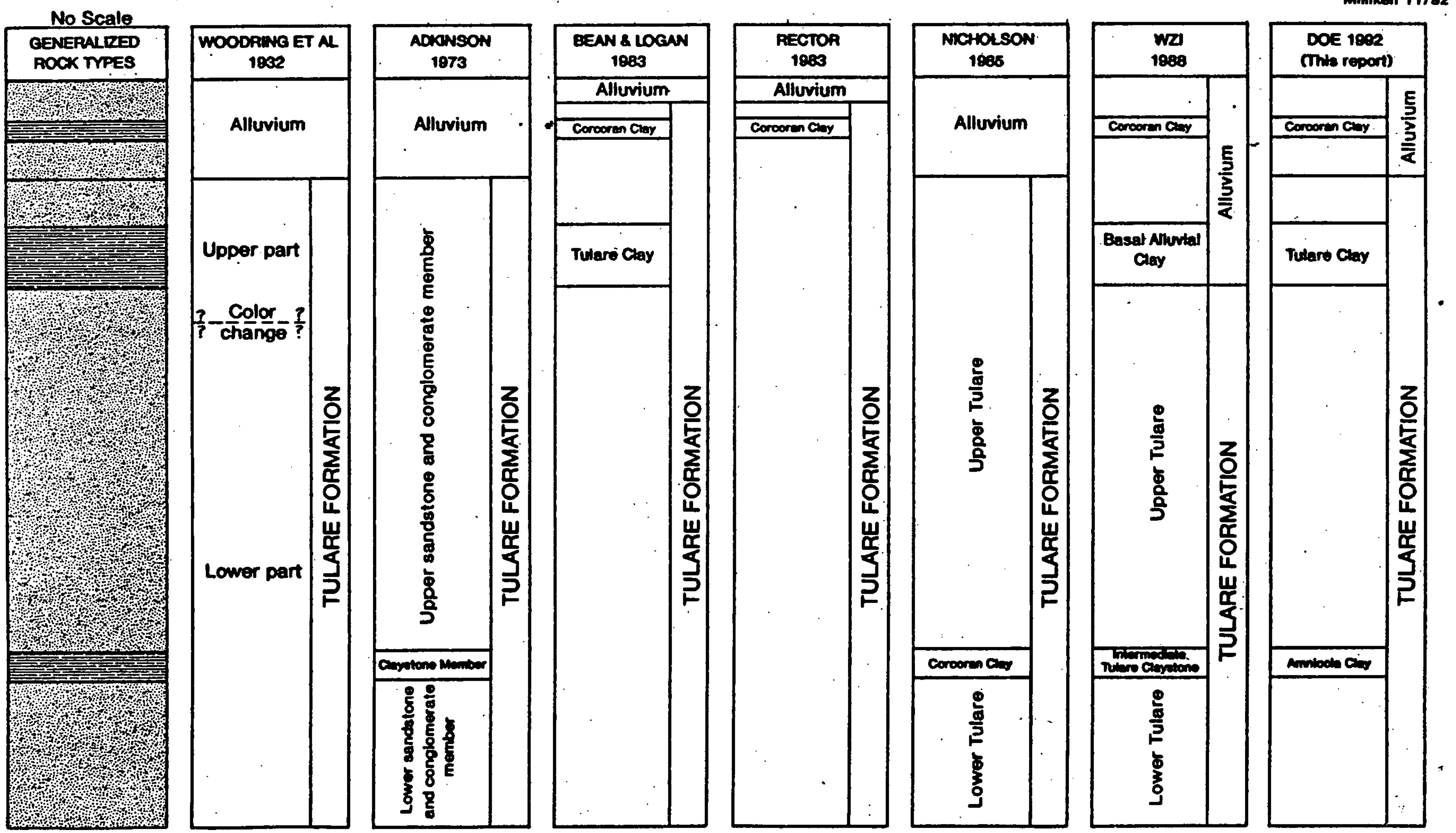

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Figure 2

subsurface data existed. Woodring selected a gray sand/buff silt contact as "lower part"/"upper part" of the Tulare Formation in 23R (T. 30 S., R. 23 E.) as a type section. Carrying this contact around NPR-1 presented a huge problem to Woodring and others (1932) because of the large number of similar color changes throughout the exposed Tulare section. Woodring's correlation problems were evident in his text (from p. 17-18):

> "The upper part of the Tulare formation (sic) consists of alternating beds of sand and hardened mud. The lowest buff mudstone in the eastern part of the hills was mapped as the base of the upper part." "....this bed is continuous over the eastern third of the hills, at least along the crest and north slope, where it is well exposed. In the western part of (5G and 6G) this bed is not so prominent, and in part of this area the lowest buff bed lies at a lower level. Farther west the lowest buff mudstone lies higher in the section, owing to a change in color, apparently at this horizon. The lensing out is clearly shown in (24R) and adjoining parts of the north slope. East of (24R) the lowest buff mudstone over a distance of several miles lies 40 to 50 feet above..limestone B, which is at the top of the lower part of the Tulare formation. On the east slope of the high ridge in the middle of (24R), however, this bed lenses into sand, and the first buff mudstone above limestone B lies about 40 feet higher. Farther west on the ridge in (24R) this bed in turn disappears, and a search for a satisfactory mudstone to map as a base of the upper part leads higher and higher in the section to a bed 125 feet above limestone B. In the western third of the hills a grayish mudstone lying 60 to 80 feet below the lowest prominent buff bed was mapped as the base of the upper part in an attempt to maintain the same stratigraphic level as farther east, for, according to the position of limestone B near by, the change in color seems to take place higher in the section."

Woodring and others (1932) did not have the benefit of fresh exposures in road and well pad cuts. Consequently, modern field studies should be more definitive in terms of picking and correlating contacts. Indeed, field work for this current report has shown inconsistencies in Woodring's mapping. Numerous similar gray sand/buff silts contacts can be present over a 200-400 foot exposed section. Mapping of these units requires physically walking the contact, and correlating any one of these contacts to Woodring's 23R type section was clearly beyond the scope of his study. Woodring's structure map uses as a datum a limestone that is apparently not present over most of NPR-1, compounding the correlation difficulties.

Other than limestones A and B, and an admittedly tenuous upper part/lower part distinction, Woodring did not map or formally recognize unique beds or bed groups within the Tulare Formation. Nor did he verify his structure contour map by compiling direct measurements of bedding attitudes. Except for areas where he had relatively good control (i.e., 23R, 24R, 3G), Woodring's geologic map should be considered highly generalized, especially in the 7G/18G area.

Adkinson (1973) divided the Tulare Formation (at the 525-30R location) into two thick sandstone and conglomerate members separated by a 91 ft "claystone member" (figure 2). This "claystone member" is an important Tulare marker on the south flank of NPR-1.

Gastropod tests questionably identified as *Amnicola* were reported in the claystone. Adkinson did not reference or in any other way acknowledge Woodring and others (1932).

In their treatment of the Tulare Formation, Maher and others (1975) simply regurgitated the descriptions of Woodring and others (1932) and Adkinson (1973). Through a series of structural cross sections, Maher shows the usefulness of the claystone member as a correlation tool. Like Adkinson (1973), Maher did not carry forth Woodring's definition of the Tulare's upper part/lower part. Maher and others (1975) did acknowledge Woodring's 23R type section, but did not specifically refute or support Woodring's upper/lower (Tulare Formation) classification. Adding to the confusion, Maher and others (1975) included Woodring's 23R type section in the text, and Woodring's geologic map, unchanged, as a plate (their plate 3).

Bean and Logan (1983) studied groundwater movement and quality in the lower westside of San Joaquin Valley, including Buena Vista Valley (adjacent to the south flank of NPR-1). Their report includes several structural cross section sketches, including the north flank of NPR-1 and Buena Vista Valley. Bean and Logan (1983) speculate (their figure 6-1) that limestone A of Woodring and others (1932) is *above* the Corcoran clay in 26S, putting the Corcoran clay in the Tulare Formation (figure 2). Bean and Logan (1983) recognized in the Maricopa Flat area a 100 ft thick clay unit near the top of the Tulare Formation (their figure 6-3), calling it the "Tulare clay." On page 6-9 of their report, Bean and Logan note of the Tulare clay:

> "The alluvium...is underlain by a thick clay bed at the top of the Tulare Formation. Injection of brines below the clay ...is probably safe."

Published at the same time as Bean and Logan (1983), Rector's (1983) report covered a much wider area. Rector's work concentrated on mapping groundwater quality changes in the southern San Joaquin Valley over several decades. His treatment of the geology of the Tulare Formation in the Elk Hills-Buena Vista Valley area was minimal.

Rector included several structural cross sections that covered such long horizontal distances that extreme vertical exaggerations were required. The resulting distortions may have led to Rector's mis-correlations between Elk Hills and North Coles Levee. In his "30 South" cross section Rector shows the Corcoran clay at depths of about 300-400 ft and apparently in the alluvium. He correlates the clay to wells 44-24R and 314-18R on NPR-1. Despite the fact that the Tulare Formation base plunges dramatically between 44-24R and North Coles Levee, Rector shows substantially less structural relief for his correlation clay. Indeed, his "Corcoran clay" in well 44-24R is equivalent to Adkinson's (1973) and Maher and others' (1975) "claystone member." Rector's correlation between wells 44-24R and 314-18R again appears to be questionable, as his "Corcoran clay" in well 314-18R is about 120 ft above Adkinson's (1973) "claystone member."

Rector (1983) applies a hydrological definition to the Corcoran clay as the bed separating the unconfined aquifer from lower confined aquifers (p. 3-5). This relationship may hold true in alluvium of the San Joaquin Valley, but not necessarily on structurally high areas such as Elk Hills where basin-fill alluvium and rocks of the uppermost Tulare Formation are not present. High on the Elk Hills structure, the "claystone member" of Adkinson (1973) separates air sands and unconfined/confined aquifers. If the hydrologic definition of the Corcoran clay is applied rigorously to structurally high areas, then a clay such as Adkinson's "claystone member," situated stratigraphically low in the Tulare Formation but structurally high, could be mistaken for the Corcoran clay. Such may be the case in Rector's 30 South cross section.

In 1985, Bechtel geologist Geoff Nicholson prepared a study based on computer simulations suggesting "probable communication between waste water disposal wells and Tulare Formation source wells." He also suggested that disposal water was probably moving from NPR-1 into alluvium of Buena Vista Valley. Nicholson recommended that all disposal be stopped immediately and that new water source wells be drilled. These were exceedingly costly recommendations that fortunately were never implemented, for Nicholson's predictions have yet to be seen. The failure of Nicholson's projections may be due to a poor understanding of Tulare Formation geology in the 7G/18G area.

In his hydrologic model, Nicholson used lithologic data from well 46-30R, the rocks of which bear little resemblance to those exposed in the 7G/18G area. Moreover, the model assumed horizontal permeabilities between 691 and 3000 md and failed to note that interbedded clays, when saturated, have permeabilities of essentially zero, thus negating lateral groundwater movement across dipping beds. Nicholson (1985) assigns the name Corcoran clay to Adkinson's (1973) Claystone member (figure 2).

In 1988, geotechnical consultants Wilson Zublin Inc. (WZI) prepared a groundwater geohydrology report for Valley Waste Disposal Company. In their structural cross sections between Elk Hills and Buena Vista Valley, WZI (1988) acknowledge an "...alluvial (clay) which separates the Upper Tulare and the alluvium" (p. 49). WZI put this bed in the alluvium and refer to it as "basal alluvial clay" (figure 2). The basal alluvial clay is equivalent to Bean and Logan's (1983) Tulare clay. WZI's "intermediate Tulare claystone" is equivalent to Adkinson's (1973) "claystone member." The "intermediate Tulare claystone" separates WZI's Upper and Lower Tulare (figure 2).

On page 50 of their report, WZI describes the hydrological character of their "basal alluvial clay":

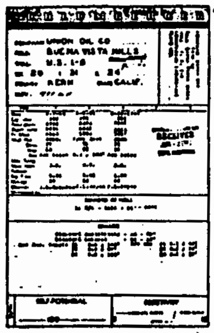
> **"As an area becomes saturated, the clays become aquitards and aquicludes forming barriers to the downward migration of wastewater." "...the Upper and Lower Tulare are separated, hydrogeologically, from the surface alluvium..." "....it is safe to inject wastewaters into the Tulare..."**

Tulare Formation nomenclature of this report. There are no known previously published geologic reports on or adjacent to NPR-1 that correlate surface outcrops of the Tulare Formation to well logs. With the exception of Woodring and others (1932), none of the referenced works attempted surface mapping of the Tulare Formation. As a result of surface mapping, well log correlations, and examination of existing data for this current report, a revised Tulare Formation terminology has been established and is shown on figures 2 and 3. This nomenclature is a mixture of previously published names and informal names of local usage. On NPR-1, the Tulare Formation consists of alternating beds of gravel, sand, silt, and clay deposited under nonmarine conditions. Woodring and others (1932) and Maher and others (1975) provide good Tulare Formation background information on NPR-1 and in the San Joaquin Valley.

In the study area, gravels make good correlation beds because of good outcrop character. Unique diagnostic qualities of gravels include clast sizes and compositions, and matrix size, and color. Some Tulare Formation gravels have clast sizes that exceed 12 inches. Some clast compositions (batholithic and metamorphic roof pendant terrane) suggest southerly sources in the San Emigdio-Tehachapi Mountains area. Such "boulder beds" may have been deposited by mudflows. Other gravels consist primarily of smaller siliceous shale clasts sourced in the Temblor Range.

Tulare Formation sands are commonly very clean, well-sorted, and contain minor gravel. Sand color is generally light gray. Sands are usually too thin to map as separate units, and so are included as interbeds within gravels. Siltstones are variously clean to clayey, and unconsolidated to moderately cemented. Silt colors are generally tan to brown or buff. Clay beds are usually chocolate brown or olive drab in color, are hard, dense, and waxy in fresh appearance. Weathering results in poor exposures of clay beds. Clays can only be recognized by digging through the weathered zone or in fresh outcrops such as road cuts. Most exposures are often poor in low-relief areas because of slope wash, soil development, and vegetation cover.

<u>Upper/lower Tulare Formation.</u> Various workers over time have differed over the definition of upper and lower Tulare Formation (figure 2). It is beyond the scope of this report to resolve these differences; that determination would have no bearing on the physical properties of Tulare Formation rocks and their relation to groundwater movement.



TYPE LOG OF THE TULARE FORMATION, SOUTH FLANK NPR-1
UNION OIL 1B-20G

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Figure 3.

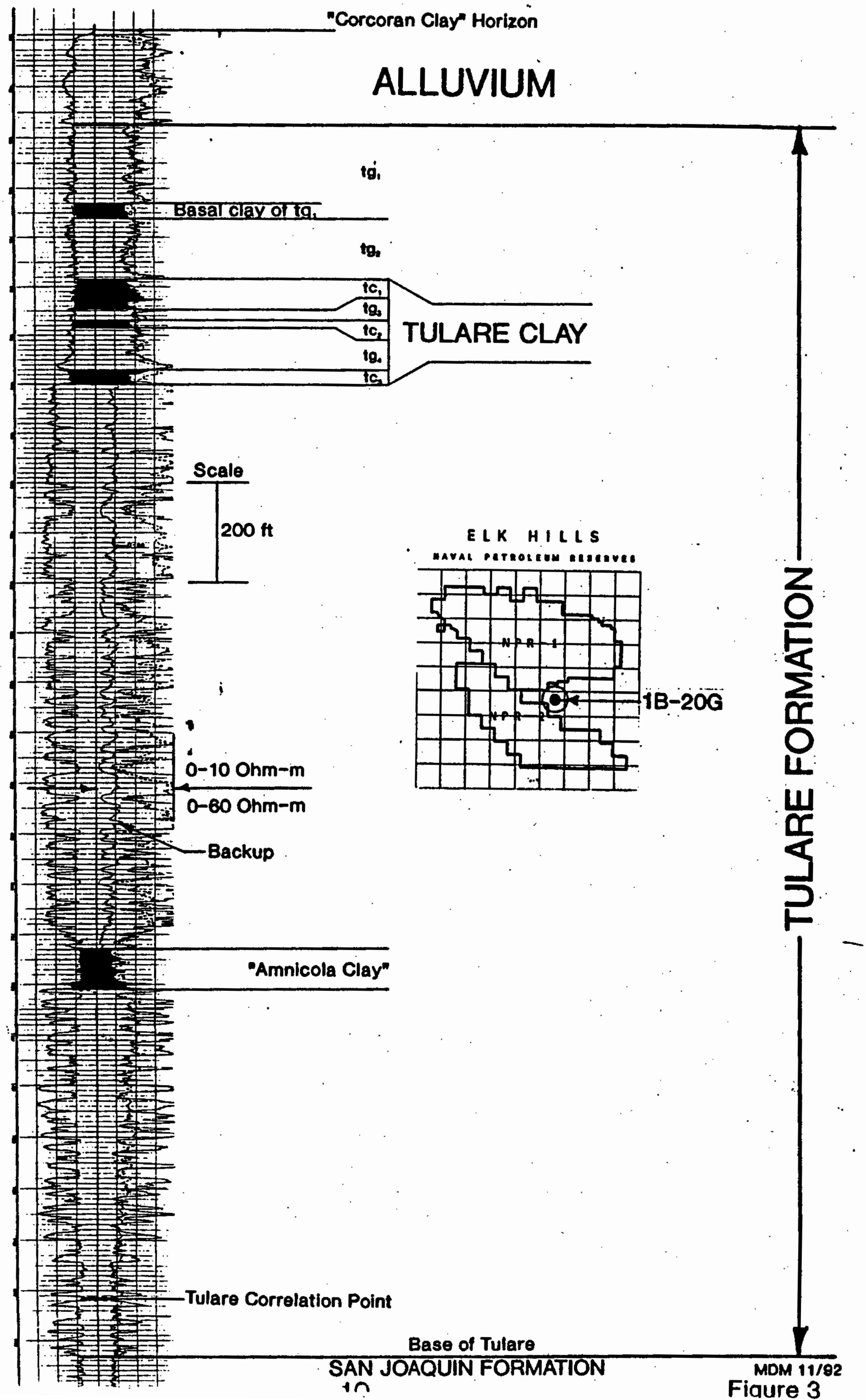

Figure 3

Figure 3.

Amnicola clay. The name "Amnicola clay" has been an informal term used locally by the Department of Energy, Chevron, and other westside oil companies. Although not referenced in their paper because it doesn't outcrop, the Amnicola clay is within the Tulare Formation's lower part of Woodring and others (1932). The clay is an excellent well log marker horizon within the lower portion of the Tulare Formation throughout much of NPR-1 and the surrounding area. It is commonly a very clean clay (figure 3) and is consistently 60-100 ft thick. This horizon is equivalent to Adkinson's (1973) claystone member, Nicholson's (1985) Corcoran clay, and WZI's (1988) intermediate Tulare claystone.

The Amnicola clay has no relationship to the "Amnicola sand" of the Tulare Formation in the Cymric Field as described by Farley (1990). The Amnicola clay has no known surface outcrops on NPR-1.

Tulare clay. A thick clay and interbedded clay-gravel unit near the top of the Tulare Formation can be seen in numerous well logs along the southern margin of NPR-1 and in Buena Vista Valley. The Tulare clay type log is from well 82WS-14B, where drill cuttings were used for an accompanying lithologic log (figure 4). Here, the Tulare clay interval includes, according to the drill cuttings log, about 250 ft of solid clay. Diagnostic clay indications in SP, resistivity, and, to a lesser degree, gamma ray logs mark the base of the Tulare clay (figures 3 and 4).

Log correlations and structural attitudes suggest the Tulare clay should crop out in the 7G/18G disposal well farm area. Doubts arose during field mapping for this report about the Tulare clay's presence on the surface when a 250 ft thick clay was not found in outcrop where predicted in the 7G/18G area. A stratigraphic section showing computed true vertical thicknesses is based on surface exposures of the Tulare Formation north of the alluvium contact (figure 5). The generic labels Gx for gravel and Cx for clays and silty clays were assigned in order of their stratigraphic position from the top of the section.

At the base of two thick gravels (G1 and G2) starts a series of interbedded clays and gravels that continues throughout the exposed section. Correlation of the field-mapped stratigraphic section (figure 5) to the nearby Union Oil 71-20G and 1B-20G well logs suggests the Tulare clay at depth is equivalent to the outcrop interval between clays C1 and C3 (figures 3 and 5). Once identified in the field, the Tulare clay interval of C1-C3 was mapped along the N½ of 18G and S½ of 7G (figure 6). On the geologic map (figure 6), rock unit names are in the form $t(c)(g)_x$ to reflect USGS geologic mapping standards.

The Tulare clay apparently changes character east of the 14B type log by the inclusion of gravel interbeds. In 18G, the Tulare clay interval includes interbedded gravels G3 and G4, which are not present in 82WS-14B (figure 4). The basal unit of the Tulare clay, C3, projected downdip

Figure 4.

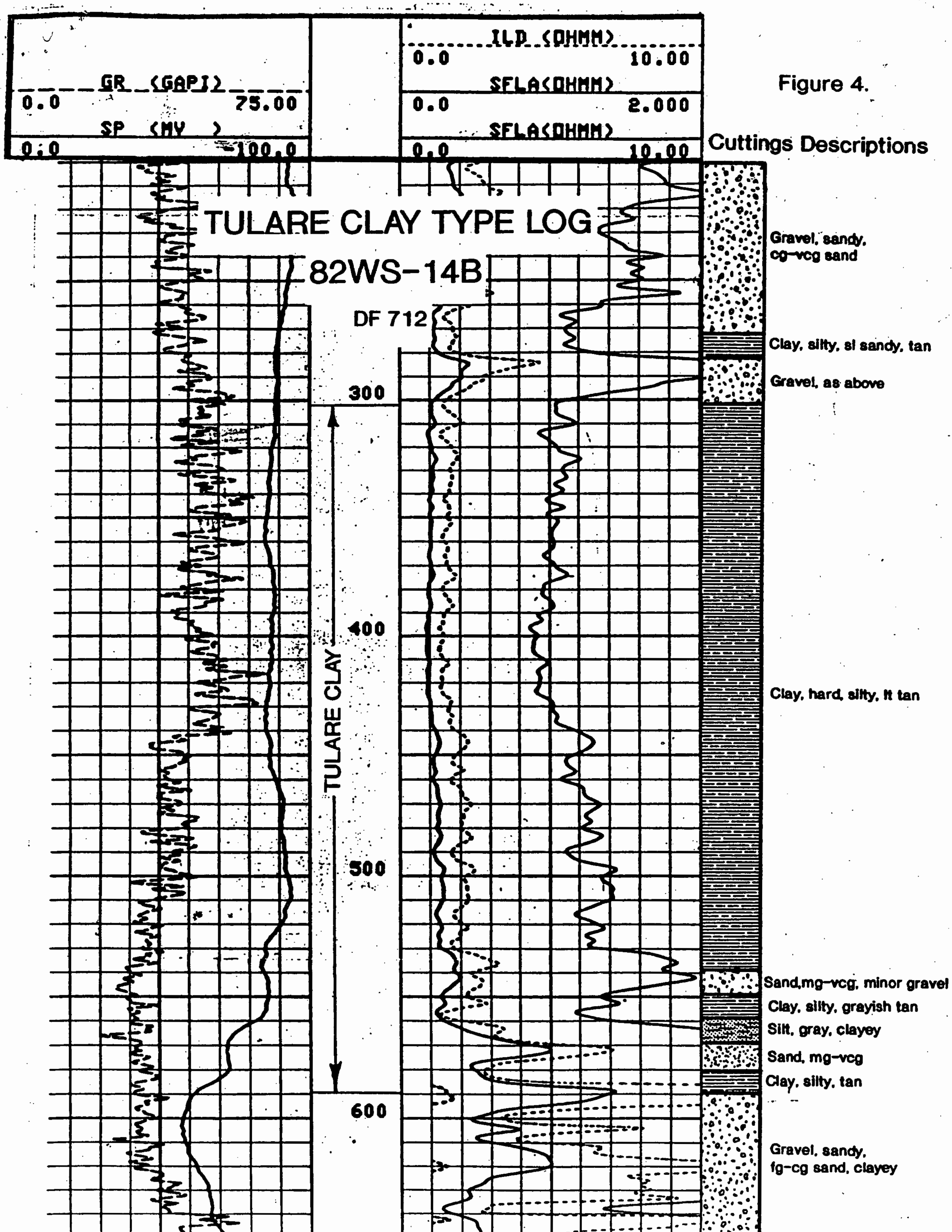

Figure 4.

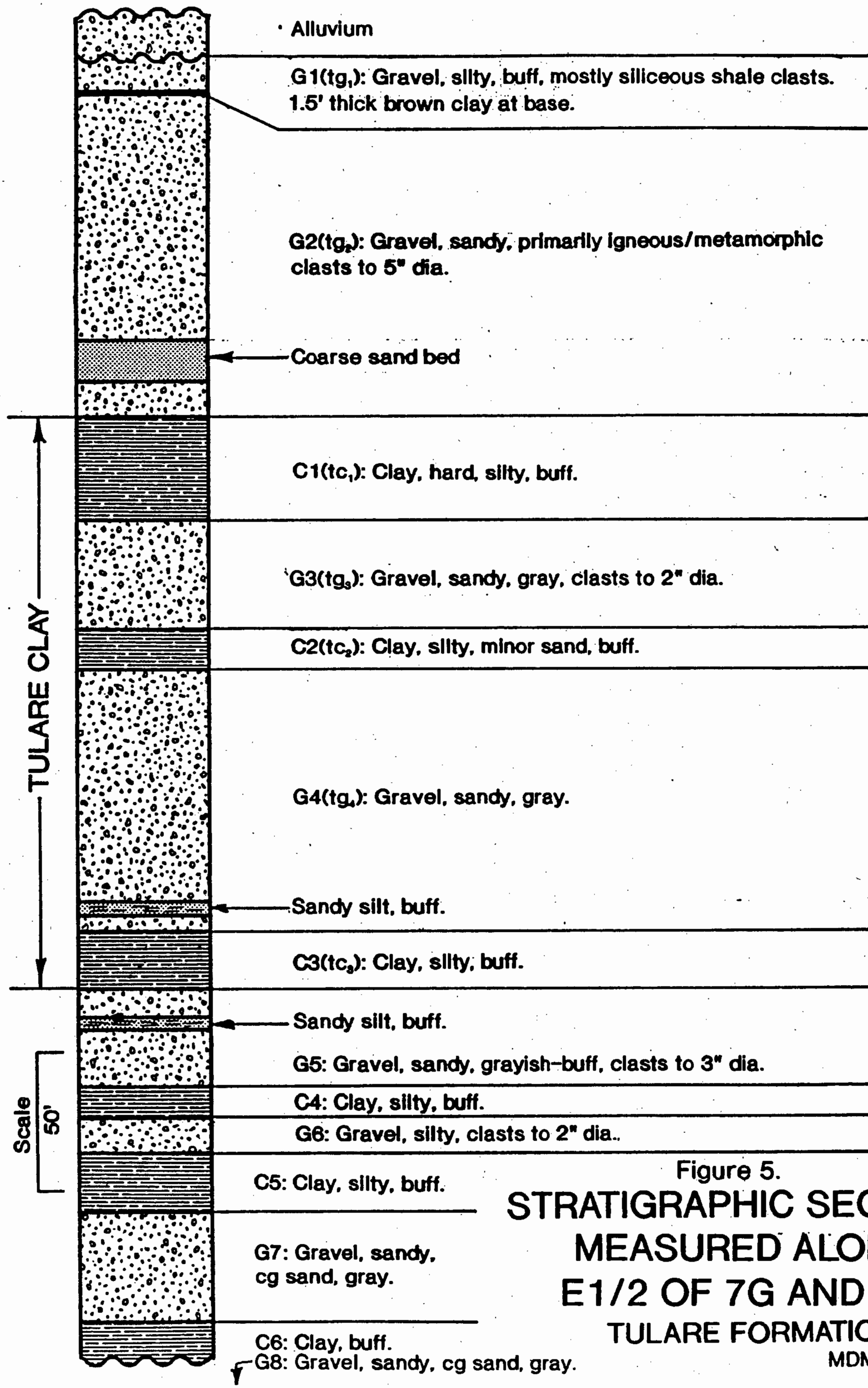

Figure 5.

STRATIGRAPHIC SECTION MEASURED ALONG E1/2 OF 7G AND 18G

TULARE FORMATION

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Figure 5.

GEOLOGIC MAP OF THE 7G/18G PW DISPOSAL AREA, SOUTH FLANK NPR-1

Figure 6.

	Qa	Alluvium, mostly reworked Tulare Formation, post-dates Elk Hills uplift.
ROCKS OF THE TULARE FORMATION	tg_1	Gravel, silty, buff color, clasts primarily siliceous shale.
	tg_2	Gravel, sandy, cg-vcg sand, gray, igneous/metamorphic clasts to 5" dia.
TULARE CLAY	tc_1	Clay, silty, buff.
	tg_3	Gravel, sandy, gray.
	tc_2	Clay, silty, minor sand, buff.
	tg_4	Gravel, sandy, gray. A 5' sandy silt is 6' above the base.
	tc_3	Clay, silty, buff.

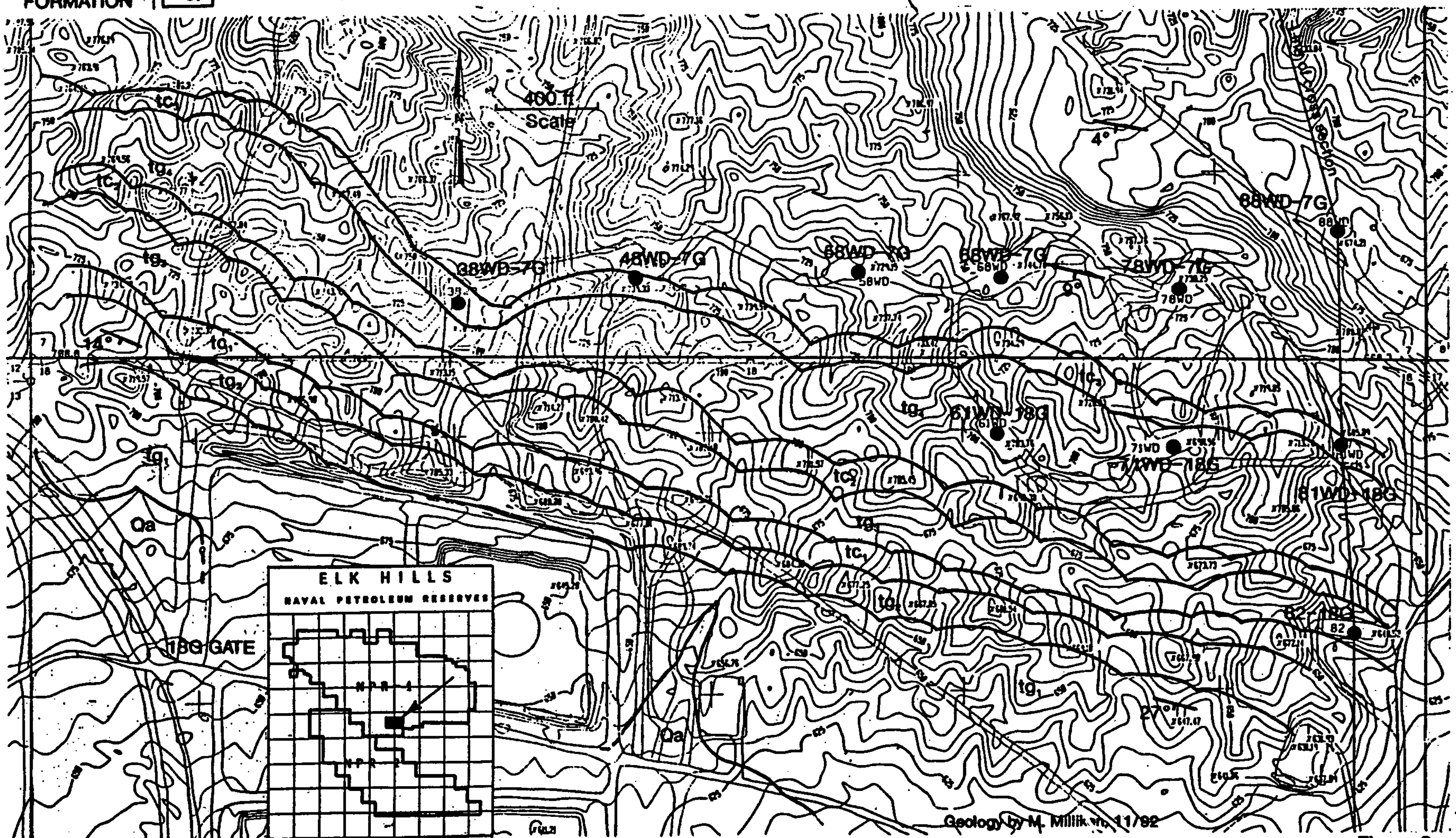

Figure 6.

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Figure 6

is clearly the rock unit responsible for the first big SP and resistivity kicks in wells 82-18G (figure 7) and 1B-20G (figures 3 and 8). C3 is probably stratigraphically equivalent to the lowermost clay unit of the Tulare clay described in the lithologic log of 82WS-14B (figure 4).

Beds comprising the Tulare clay interval dip southeastward at 9°-20° in 7G/18G area. Dips increase toward the Buena Vista Valley synclinal basin. The Tulare clay underlies gravels G1 and G2 of the Tulare Formation and are within the upper part of the Tulare Formation as defined by Woodring and others (1932). This conclusion conforms with that of Bean and Logan (1983), but not that of WZI (1988), who define the Tulare clay (their basal alluvial clay) as being in the alluvium.

Between gravels G1 and G2 is a one to two foot bed of hard, brown clay (figure 5). The clay's matrix color more closely resembles G1's color, so it is termed a basal clay of G1. This clay apparently thickens rapidly basinward and becomes about 30 ft thick in well 1B-20G (figure 3).

Alluvium. As mapped in figure 6, alluvium on the south flank of NPR-1 is composed of modern sediments reworked from Tulare Formation outcrops and resting unconformably upon gravel G1 (figure 5). Alluvium exposed on the surface in the study area does not have a structural dip. Picking the subsurface contact between the alluvium and Tulare Formation is highly subjective. For this report, the alluvium/Tulare Formation contact is nominally picked at a depth of 473 ft in well 1B-20G (figure 3). Both SP and resistivity log characters change at this depth suggesting increased porosity in the overlying uncompacted rocks.

Corcoran clay. Much work has been done trying to characterize the Corcoran clay in the southern San Joaquin Valley. The Corcoran clay is not known to outcrop on the flanks of NPR-1, nor is it apparent in NPR-1 well logs. Structural cross sections by Rector (1983) and WZI (1988) through the Buena Vista Valley identify the Corcoran clay as being very shallow. In the 71-20G log, both Rector and WZI concur on the Corcoran clay pick at a depth of 413 ft. Log correlations between wells 71-20G and 1B-20G show the base of the Corcoran clay to be at the top of the logged interval in well 1B-20G (figure 3). The casing for well 1B-20G was probably set at the base of the clay.

The Corcoran clay is above the alluvium contact defined on the 71-20G well log WZI (1988). Cross sections of WZI (1988) show the Corcoran clay as not structurally deformed, suggesting deposition after the last major uplift of Elk Hills. Rector (1983) shows the Corcoran clay to be tilted on the north flank of NPR-1. His correlations, as discussed earlier, are questionable. Being in the alluvium, the Corcoran clay would have no effect on disposed PW movements within or adjacent to NPR-1.

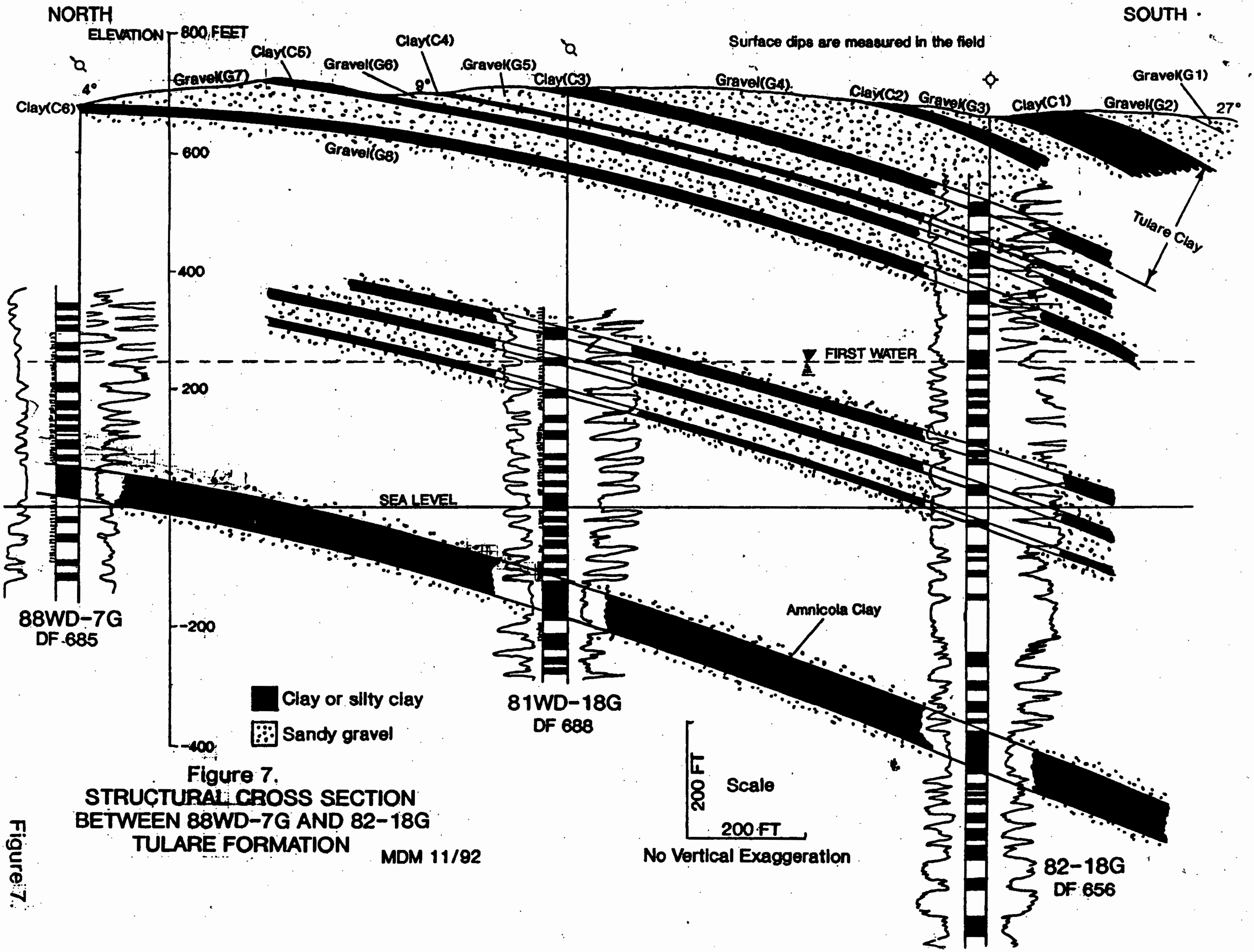

Figure 7.
STRUCTURAL CROSS SECTION
BETWEEN 88WD-7G AND 82-18G
TULARE FORMATION

Figure 7.

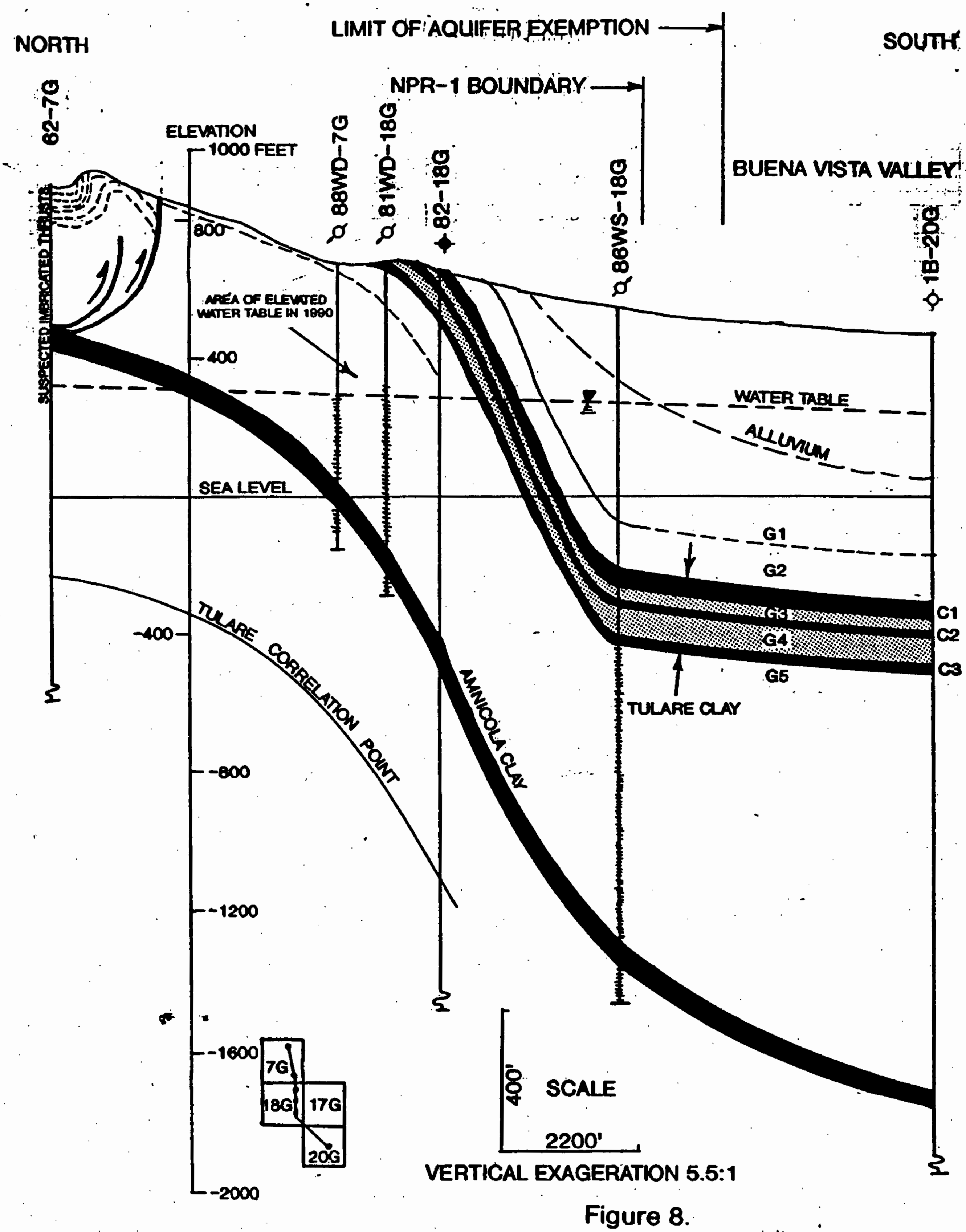

Figure 8.
STRUCTURAL CROSS SECTION
SOUTH FLANK NPR-1 TO BUENA VISTA VALLEY

V. Structure of the Tulare Formation within the study area.

Bedding attitudes taken from outcrops show the Tulare Formation as gently dipping (4°-9°) in the S½ of 7G. The ground surface north of the disposal area is a 4° dip-slope. Dips begin to steepen rapidly at the 7G/18G section line and exceed 27° in the G1 gravel at the southern limit of exposures (figure 6). Dips continue to be steep in the subsurface (figure 9) and appear to decrease significantly in Buena Vista Valley between wells 86WS-18G and 1B-20G (figure 8).

North of the study area, in N½ 7R, is an interesting fold in the Tulare Formation that is arguably bounded on the south by a normal fault or high angle reverse fault (figure 8). Alternately, younger Tulare Formation beds may post-date the folds and lap onto the flanks unconformably. Based on limited field mapping, the fold has no impact on the study area. No evidence for faulting was observed within the study area.

VI. Relationship of Tulare Formation geology to south flank groundwater movement.

Produced water is being injected into an interval of the Tulare Formation between the Tulare clay and Amnicola clay (figures 7 and 8). Source water is produced down-dip from the same stratigraphic interval (figure 8). Anomalously high groundwater elevations over the past ten years within the disposal well farm (see figure 8 and discussion by Phillips (RMCI, personal communication, 1992) suggest that disposal water is mounding and spreading laterally along strike. The following discussion illustrates how the Amnicola and Tulare clays contain the subsurface movement of disposed water.

As noted by Bean and Logan (1983) and WZI (1988), the Tulare clay forms a barrier to groundwater migration between the Tulare Formation and alluvium. Thus the 7G/18G disposal wells are hydrologically isolated from the alluvium by clay beds of not only the Tulare clay, but numerous other clays above and below the Tulare clay interval (figure 5).

Phillips (RMCI, personal communication, 1992) presents directly measured water quality data from NPR-1 wells showing that the Amnicola clay forms an aquiclude between waters of distinctly different salinities. Data and conclusions revealed by Phillips (RMCI, personal communication, 1992) can be verified by well log resistivities. Resistivities of water-saturated clean sands (R_o) provide qualitative indications of formation water quality. A compilation of R_o values within the alluvium and Tulare Formation is presented for Union Oil wells 1B-20G (figure 10) and 71-20G (figure 11). R_o trends are similar for both wells, and suggest relatively poor water quality above the Tulare clay. Water quality immediately below the Tulare clay improves drastically, but decreases with depth. Below the Amnicola clay, water quality decreases significantly.

Figure 9.

STRUCTURE CONTOUR MAP ON BASE OF TULARE CLAY SOUTH FLANK NPR-1

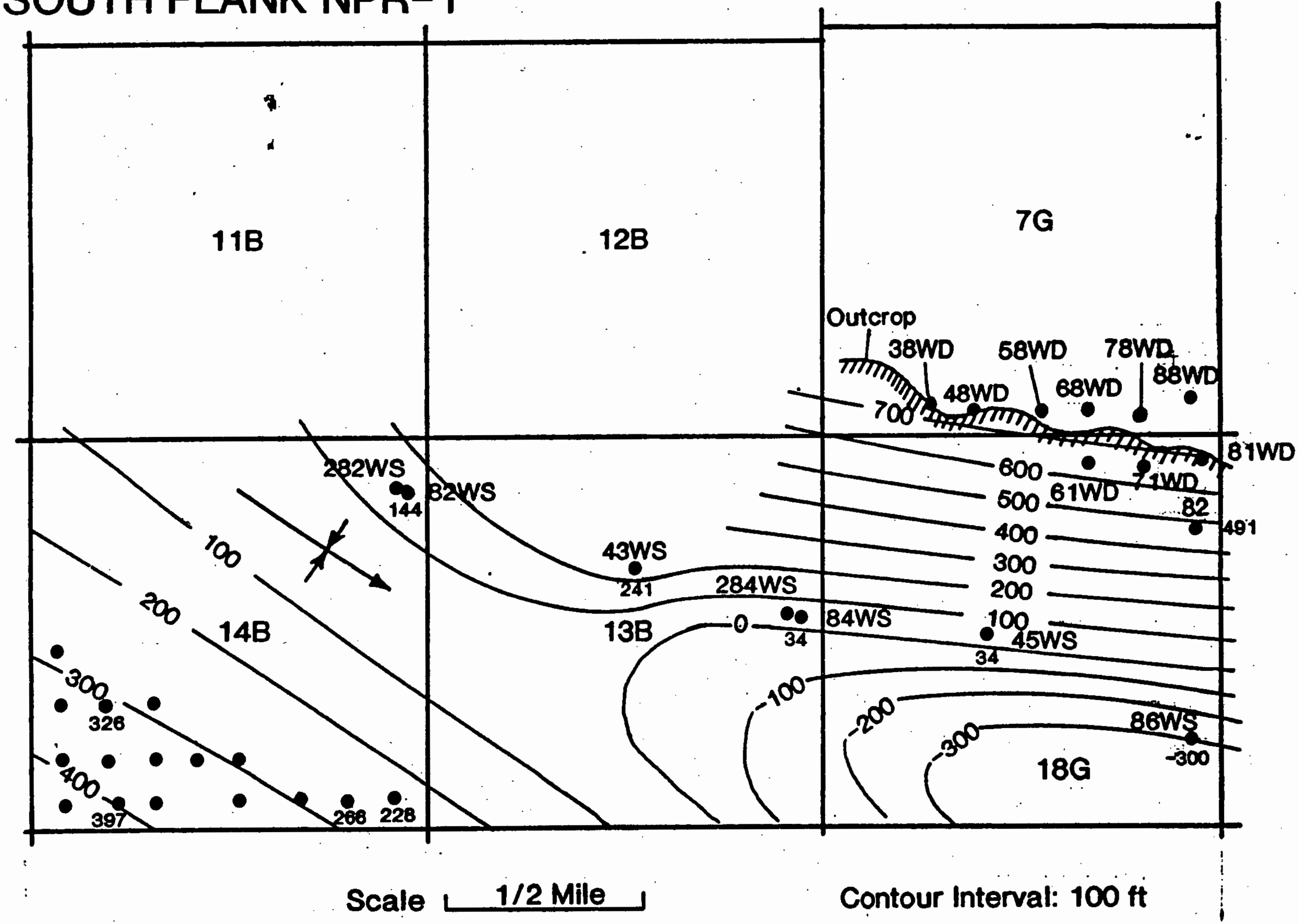

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Figure 9

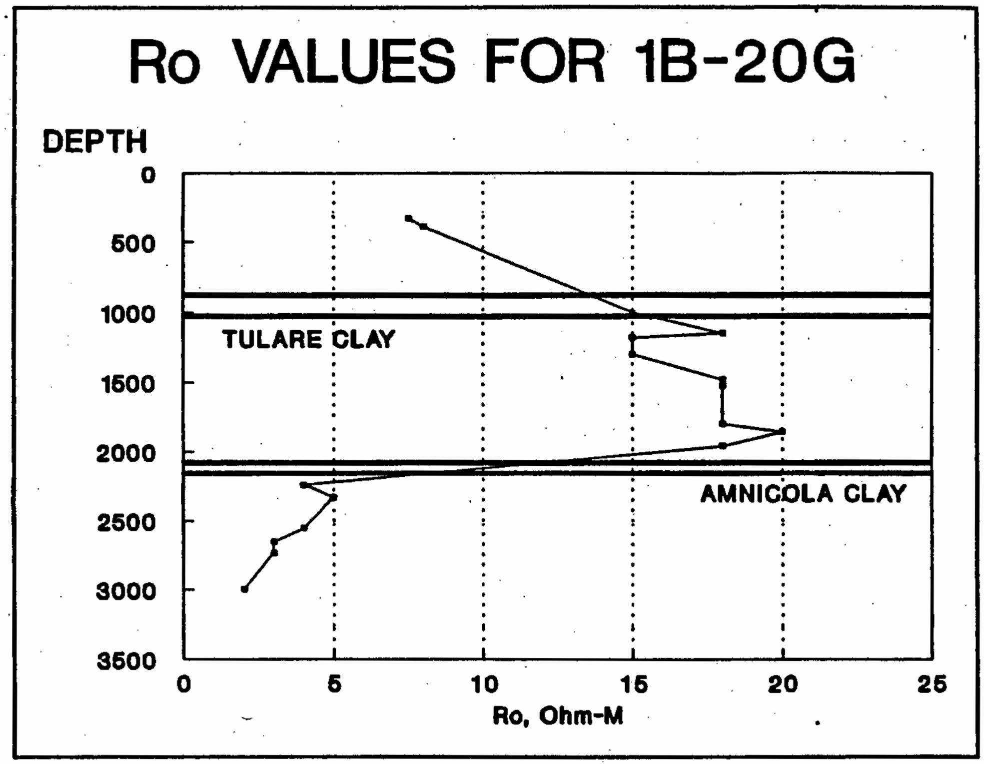

Figure 10. Resistivities of water-saturated clean sands (R_o) yield qualitative measures of formation water resistivities. Salinity increases with decreasing R_o.

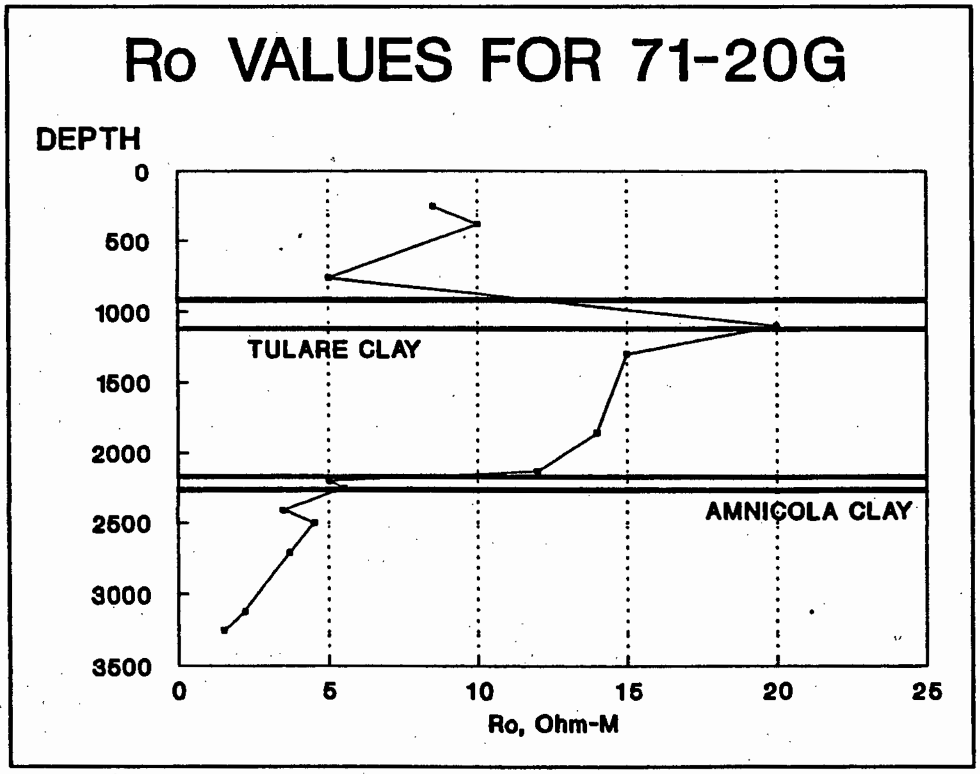

Figure 11. R_o relationships of 1B-20G are repeated in 71-20G. The Tulare and Amnicola clays clearly form aquicludes between waters of differing qualities.

These data support Phillips' (RMCI, personal communication, 1992) finding that the Tulare and Amnicola clays separate aquifers of greatly different water qualities, and underscore this report's conclusion that Tulare Formation clays are barriers to groundwater movement across beds.

The alluvium of Buena Vista Valley, from which agriculture water production is obtained, is geohydrologically isolated from the Tulare Formation disposal wells and is in no immediate danger of contamination. Given the vertical interval over which the water source wells are perforated, Tulare Formation porosity, and current rates of production, well drainage radii will theoretically not reach the PW disposal plumes for many decades, possibly beyond the 21st century. As there are no known offsite pressure sinks within the Tulare Formation, produced water is not expected to migrate off NPR-1 through the Tulare Formation.

VII. Opportunities for further data acquisition.

Detailed geologic maps of key Tulare Formation horizons such as the Tulare clay should be prepared, with correlations being carried, to the degree possible, around NPR-1. A key stratigraphic horizon should be defined that is easily identified in the field and is widespread over NPR-1. Bedding attitudes need to be compiled from outcrops and road cuts throughout NPR-1. More detailed correlation work is necessary from the south flank of NPR-1, across the south flank en-echelon Tulare Formation fold belt, over the crest of Elk Hills, and down the northern flank. This work would be of critical value to north understanding north flank NPR-1 geohydrology.

Further work will be required to characterize the south flank and other Tulare surface folds. Tulare Formation faults mapped in the subsurface should be projected to the surface and field checked. Detailed structure and geologic maps can then be prepared based on direct field measurements of a substantive datum.

New wells drilled on the flanks of NPR-1 for any purpose should be planned with very shallow log runs to glean more Tulare Formation subsurface data. Dipmeter data would be of particular value. Water source and disposal wells should have on-site geologists describing and logging drill cuttings. More shallow subsurface data will allow surface exposures to be more accurately correlated with well data.

UNITED STATES DEPARTMENT OF ENERGY
NAVAL PETROLEUM RESERVES IN CALIFORNIA

TECHNICAL REPORT

GEOLOGY OF THE TUPMAN AREA, NAVAL PETROLEUM RESERVES #1 KERN COUNTY, CALIFORNIA

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December, 1993

12/22/93

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GEOLOGY OF THE TUPMAN AREA,
NAVAL PETROLEUM RESERVES #1
KERN COUNTY, CALIFORNIA

Mark Milliken

December, 1993

I. Management Summary

The purpose of this project is to investigate and geologically map the various rock units of the Tulare Formation (hereafter referred to as "Tulare") and surficial sediments of the Tupman area, NE flank NPR-1. The area includes sections 25S, 26S and portions of 23S and 24S, T. 30 S., R. 24 E. Included in the study area are the 23S sumps, the 25S LACT site, and the town of Tupman. This effort is part of ongoing groundwater characterization studies in response to NPRC Tiger Team (91) Corrective Action EAP-013, "Characterization of the Hydrologic Regime," for Finding No: GW/CF-3.

The Plio-Pleistocene Tulare consists of gravel, sand, silt, clay, and limestones. The Tulare depositional environment was a broad apron of coalescing alluvial fans and deltas emanating from mountain ranges to the west and south. Rivers shifted back and forth along the plain, abandoning old channels and scouring new ones. Fining upward sequences culminate in quiet water clay and limestone, suggesting channel abandonment. Subsequent coarsening upward cycles suggest diversion of stream channels into the lake basins. The mapping of limestone outcrops assists in determining bedding attitudes.

Surficial alluvial deposits postdate the Tulare and include older fan deposits, older alluvium, flood plain deposits of the ancestral Kern River, and modern alluvium. Older fan and alluvium deposits were laid down during periods of high runoff, possibly coincident with Sierran glacial events within the past 1 Ma (million years). No datable materials have been found to provide absolute age dates of any mapped rock units.

Structural features include faulting and minor folding, primarily limited to the Tulare. The Tulare in general dips to the northeast at 4°-7°, with dips as much as 19° near faults. Major faults oblique to the Elk Hills anticlinal axis and mapped by previous workers are confirmed to exist in the study area, but are buried by surficial deposits younger than the Tulare.

The importance of smaller Tulare faults seen on the surface is unknown due to a lack of subsurface data. The name "Tupman Fault" is given to a spectacular fracture cutting post-Tulare fan deposits with observed strike-slip and vertical displacements. The Tupman Fault (previously referred to by Woodring and others (1932) as an "earthquake crack") does not cut surficial deposits younger than the Tulare fan.

Brea deposits of solidified oil and sand underlie modern drainages. The fluids have long stopped flowing and the deposits do not appear to endanger plants or wildlife. According to previous studies on NPR-2, hard brea in natural channels should remain intact. Other areas of concern include the 23S sump and 25S LACT sites.The cyclic fining-upward sequences of the Tulare would greatly restrict any downward movement by groundwater. Faults appear to act as barriers to lateral groundwater movement and may be in part responsible for a groundwater mound along the crest of the Elk Hills anticlinal structure.

II. Conclusions and Recommendations

Conclusions. Geologic mapping of the NE flank area of NPR-1 shows that the relationships between the Tulare and several mappable surficial units to be far more complex than simple Tulare/alluvium contacts depicted by previous workers. Faulting and folding in the Tulare may be related to wrenching, thrusting, or gravity mass movement. Tulare groundwater is connate and not moving off NPR-1 due to structural control and a lack of recharge. Although surface discharges of produced fluids have occurred in the past, none are currently in effect within the study area.

Recommendations. Existing data on Tulare/alluvium contacts on NPR-1 need to be reconsidered in light of much more complex stratigraphic relationships uncovered through detailed surface mapping. Faults exposed at the surface, particularly the Tupman Fault, may be groundwater barriers as suggested by well log interpretations of Tulare faults in an area adjacent to the study area. Brea deposits should not be remediated.

III. Introduction

Purpose and scope. Several public comments were received on the Draft Supplemental Environmental Impact Statement (DSEIS) requesting more technical work be added to support geologic and geohydrology discussions and conclusions. Moreover, a recent Elk Hills groundwater study (Golder Associates, 1990) focused on the need for further groundwater characterization in the NE flank area. This effort is part of ongoing groundwater characterization studies in response to NPRC Tiger Team (91) Corrective Action EAP-013, "Characterization of the Hydrologic Regime," for Finding No: GW/CF-3.

Location. The study area includes portions of sections 23S, 24S, 25S, and 26S, T. 30S., R. 24E., on the NE flank of NPR-1 (figure 1). Locations of interest within the study area include the 23S tank farm and percolation pits, 25S LACT facility (site), and the Town of Tupman. Much of the study area is accessible only by foot because of restricted off-road driving. Many older roads have been revegetated and subsequently closed. The long-abandoned "U" group of wells, in the S½ of section 26S, will be discussed in terms of past oilfield practices. There are only three currently producing wells in the entire study area: 382-25S, 31BM-26S, and 87BM-26S.

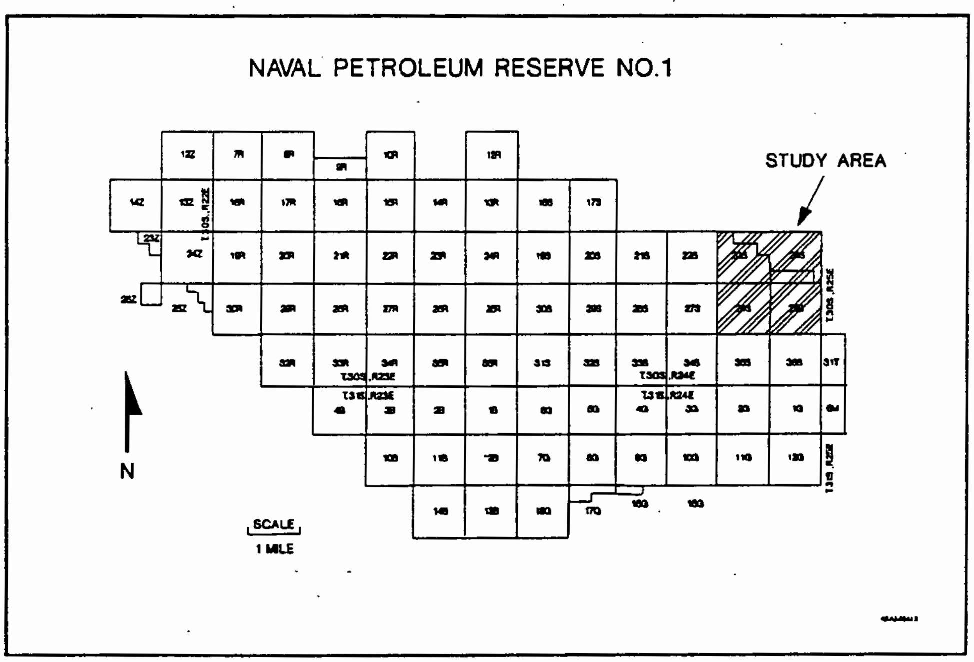


Figure 1. Location map of study area. NPR-1 is about 23 miles southwest of Bakersfield.

Methodology. Rock units are described and bed attitudes measured from Tulare outcrops in the study area. Bed contacts were walked laterally and, with the aid of air photos, plotted on a topographic base as a geologic map. Structural cross sections were prepared to confirm the presence and significance of faulting. Stratigraphic nomenclature and correlations of the cross sections were checked for conformance with previously published data.

Previous work. A number of geologic reports related to Tulare geology of NPR-1 have been written since the 1930s. Papers written prior to the 1980s were primarily concerned with pre-Tulare oil bearing rocks. In these older papers, the Tulare was perceived as having little or no economic or scientific value, and so received little attention.

Among the first and still one of the best Tulare papers directly related to NPR-1 is Woodring and others (1932). This paper has formed the foundation of most thinking over the years about Tulare geology on NPR-1. Adkinson (1973) studied 1163 feet of Tulare core from well 526-30R (T. 30 S., R. 23 E.). Maher and others (1975), like Woodring and others (1932) and Adkinson (1973), were primarily concerned with pre-Tulare oil producing rocks.

Bean and Logan (1983) studied west side hydrogeologic conditions under contract to the California State Water Resources Control Board. Rector (1983) looked at Southern San Joaquin Valley hydrologic conditions for Western Oil and Gas Association (WOGA). In 1988, Wilson Zublin Incorporated (WZI) prepared a report for Valley Waste Management, a consortium of west side oil companies cooperating to manage the disposal of produced water.

Golder Associates (1990) prepared a Groundwater Monitoring Plan for NPR-1. This report did not adequately address either Tulare stratigraphy or structure in the NE flank area. Nicholson (1985), for the Unit Operator, presented a geologic study of the Tulare in the 7G/18G area that did not adequately address stratigraphy. Milliken (1992) mapped a small area of Tulare on the south flank of NPR-1 in the 7G/18G produced water disposal area. Phillips (1992) looked at historical changes in groundwater quality in the south flank NPR-1 disposal area.

IV. Stratigraphy of the Tulare within the study area.

Problems of mapping the Tulare. The most detailed attempt at mapping individual units within the Tulare on NPR-1 was made by Woodring and others (1932). Their study was constrained by the lack of fresh surface exposures and subsurface data. For a type section, Woodring selected a gray sand/buff silt contact as "lower part"/"upper part" of the Tulare in 23R (T. 30 S., R. 23 E.). Carrying this contact around NPR-1 presented a major problem to Woodring and others (1932) due to large numbers of similar color changes throughout the exposed Tulare section. Milliken (1992) gives a discussion of the problems and inconsistencies encountered by Woodring and others (1932) in attempting to map and characterize the Tulare.

Maher and others (1975) noted the "...scarcity of marker beds in the monotonous succession of similar lithologies making up the exposed Tulare Formation." The geologic map of Woodring and others (1932) shows contacts between the upper and lower Tulare within the current study area, although the contact was recognized in the current study. Woodring's marker beds "Limestone A" and "Limestone B" were not mapped in the study area, although a number of rather thick limestones do outcrop and were mapped for this current study. Woodring and others (1932) show an "upper part"/"lower part" Tulare contact in section 26S.

No consistently well-exposed marker beds were found in the study area, confirming the observations of Maher and others (1975) noted above. Limestones are good control beds for only as far as they can be walked. Similar repetitive limestones in the stratigraphic column, lateral facies changes, and pinch-outs make correlations over large distances (> ½ mile) and across faults very difficult. In an attempt to identify possible marker beds, several measured sections were taken across various mapped limestones (plate 1). The limestones make good beds upon which local structural attitudes can be measured.

Tulare undifferentiated is labeled as "tu" on the geologic map (plate 1, in pocket). Tulare age, generally considered late Pliocene and early Pleistocene, has been debated since the 1800s. Fossils commonly give contradictory age estimates, but strongly suggest Pliocene age. Frink and Kues (1954, p. 2364)) give a good historical perspective on the debate up to that time. Absolute age dates from NPR-1 fossil finds will be discussed later.

Rocks composing the Tulare

Sands and gravels. Volumetrically, unconsolidated sands and gravels compose the bulk of Tulare rocks exposed. Because of shallow dips, a relatively small (probably <100 ft.) stratigraphic column is exposed. Poor exposures due to soil and slope wash result in minimal stratigraphic data derived from exposed sections, such as sedimentary structures. Tulare gravels occupy braided channels on fan aprons that commonly shifted position laterally. The lateral extent of individual gravel units and facies were not mapped in this study due to poor exposures.

There are at least two facies of gravels apparent in the study area and elsewhere on NPR-1. Debris flows exhibit randomly oriented and mud matrix supported clasts, primarily of silicious shale composition. Another type of gravel exhibits fluvial sedimentary structures such as cross-bedding and scouring typical of braided streams (figure 2). The pebbles are clast-supported and bedding is normally graded. The coarse sand matrix is mostly clean, well sorted, and graded.

Figure 2. Crossbedded and scoured braided stream channel gravels of the Tulare at well 388-35S. Paleocurrent is eastward.

An abundance of metamorphic, volcanic, and granitic clasts in the Tulare suggests origins to the south, possibly from the San Emigdio Range. Roughly half of the pebbles are siliceous shale of the Temblor Range. Paleocurrent directions from larger imbricated siliceous clasts suggest an eastward flow direction. This type of gravel, with the coarse sand matrix, is more prolific on the south flank of NPR-1, where clasts are distinctly larger, often exceeding 12 in. in length. This evidence suggests the presence of an Elk Hills structural high during the time of Tulare deposition. Evidence in other areas suggests that Tulare gravels were also derived from the east in the Sierra Nevada Range (Tor Nilsen, oral communication, 1993). Given their potential to control groundwater distribution, the channels provide an opportunity for further mapping projects.

Silts and clays. Silts and clays occur in fining upward intervals stratigraphically between gravels and limestones. These fine grain sediments are difficult to see in the field except in fresh road or pad cuts. The silts can be in an unconsolidated flour-like state, or lightly cemented requiring a rock hammer to expose. Clays are commonly dark olive brown or grayish green in color and waxy in texture. When wet, clays lose their shear strength, causing slope failures and creep on steeper hillsides. These features makes clay tops quite apparent along ridge flanks, especially when underlying limestone.

Limestones. Although not mapped by Woodring and others (1932), there are a number of limestones exposed in the study area (plate 1). Limestones are white in color and can be several feet thick. Figure 3 shows a typical limestone exposed at the well 13-25S pad cut. This particular limestone is the lower of two limestones about 15 vertical ft apart. This couplet is mapped over much of the S½ section 25S (plate 1).

Limestones are the most important rock units in the study area because of their relative ease of mapping. Several decades ago, limestone was quarried for unknown purposes, possibly by mining claimants as assessment work (figure 4). Only small quantities of limestone appear to have been mined.

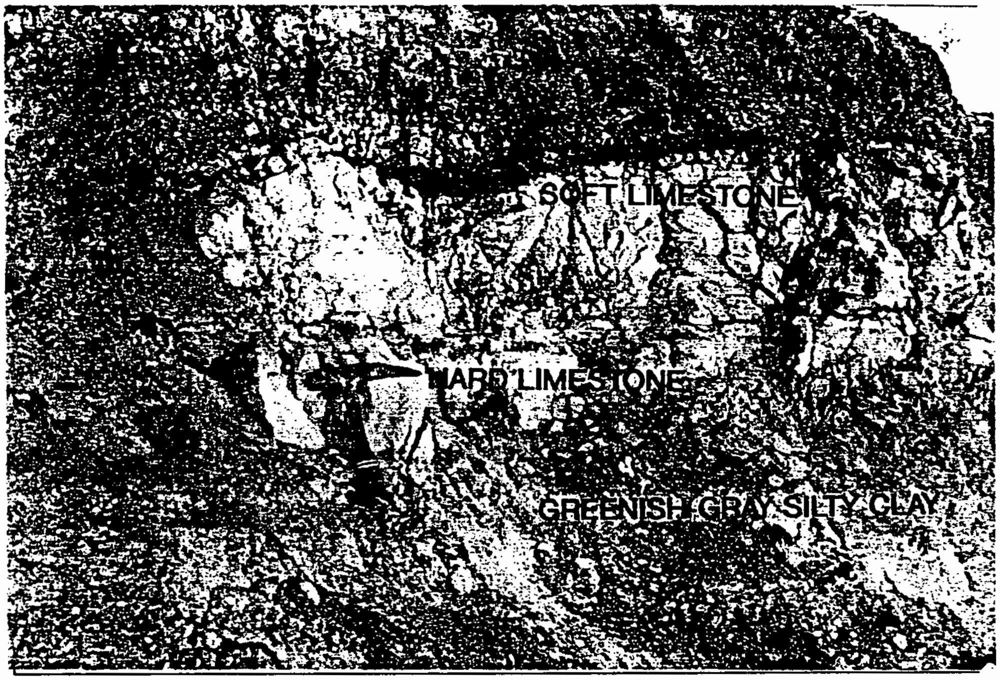


Figure 3. Photo P1. Location: 1620' E, 4990' S from NW 25S (see plate 1). Limestone exposed at well 13-25S pad cut is overlain and underlain by silty clays.

Figure 4. Photo P2. Location: 2700' W, 1800' S from NE 26S. Summer hire student Rachelle Carlos in one of many limestone quarries of unknown age and purpose.

Being resistant to weathering, limestones commonly form ridge caps, topographic ledges, and abundant float. Figure 5 shows a typical relationship between limestone, gravel, and clay along a ridge top.

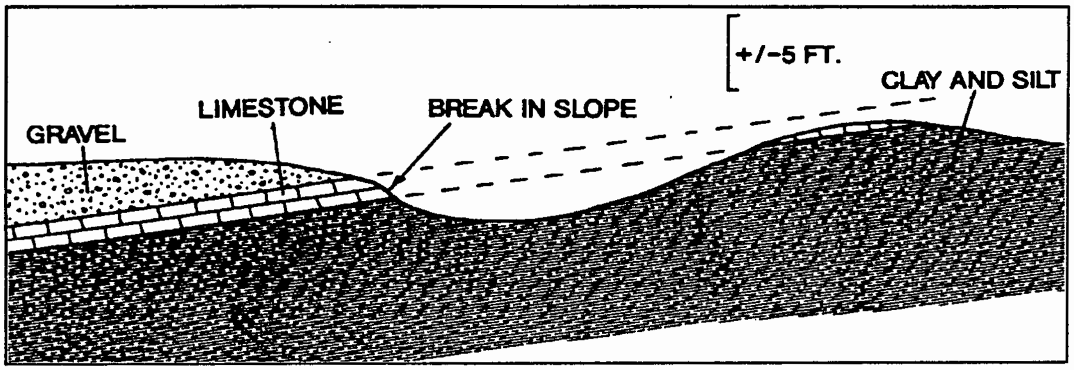


Figure 5. Diagrammatic cross section depicting relation of lithologies to geomorphology along ridge crests in the Tulare.

The hard, flat limestone tops often provide good surfaces on which bedding attitudes can be measured directly (figure 6). Clays underlying the limestones creep when moistened, often causing concave-shaped clay aprons downslope from the contact (figure 7). Vegetation is not attracted to the clay aprons, which form prominent barren zones easily seen in the field.

Gypsum-cemented sands occasionally overly the limestones, but mostly occur at the top of clay beds. The gypsum is a secondary mineral leached from Tulare gravels and precipitated out as downward percolating groundwaters perched on impervious clay beds. These resistant sands also make good field mapping units (plate 1). Selenite plates on the flanks of ridges provide good float indicators of the tops of fining-upward sequences.

Figure 6. Photo P5. Location: 2120' W, 1430' S from NE 26S. Rachelle's hand rests on a limestone top dipping 19° east into a possible fault.

Figure 7. Photo P3. Location: 2650' W, 1800' S from NW 25S. Limestone forming a resistant ledge. Underlying clay forms a concave "apron" downslope from the contact.

Measured sections. Nine measured sections were recorded in various limestones throughout the study area (plate 1). Figure 8a-i depicts these sections. Note how limestones tend to be associated with clay and silty clay. Initially, the purpose of measuring these sections was to identify unique features allowing correlations across the study area. Estimates of vertical offsets along major northeast-trending faults postulated by Woodring and others (1932). But vertical displacements appear to be so large that correlations are impossible or highly speculative..

Lateral changes in the limestones due mostly to weathering were noticed within the same beds along outcrop trends (figures 8a and 8b) that raised doubts about longer correlations. At times, the limestones are silty or weathered to a fine white soft rock that crumbles between the fingers. This weathered phase occurs at different levels of the limestones and is not a good diagnostic tool for correlation.

Clays underlying the limestones are commonly dark olive-green and are not necessarily diagnostic of individual beds. An exception is the orange-tan silty vfg sand underlying limestones in sections S5 (figure 8e) and S6 (figure 8f). These orange colored sediments are unique because of their grain size and color, and may have been oxidized by subaerial exposure prior to deposition of the limestone. This is the only case where evidence supports correlations of widely separated limestones. Nowhere else was this distinctive relationship seen. No such distinctions were noted among limestones juxtaposed across faults mapped by Woodring and others (1932).

Tulare environment of deposition. The Tulare is composed of nonmarine sediments of Plio-Pleistocene age (Woodring and others, 1932). Deposition was on fans or deltas originating to the east, south, and west. Climate during the time of Tulare deposition was pluvial, with large amounts of water transporting dense metamorphic and igneous clasts greater that one foot in length over distances of 20-50 miles. The lack of evaporites and organic materials associated with the clays suggests the Tulare lakes were never dry and had good circulation.

No evidence of swamp vegetation was found in the limestones and clays. Woodring and others (1932) found the limestones to contain *Chara*, a lime-secreting algae. Limestone concretions also occur in the silt horizons as secondary deposits from movement of groundwater. Concretions have irregular forms and conform with bedding planes in the clay.

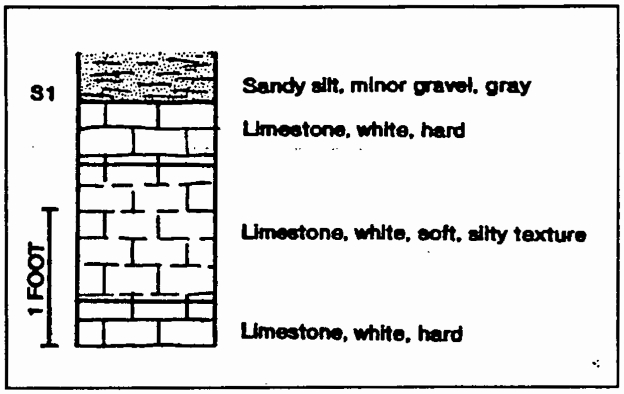


Figure 8a. S1. 600'W, 3230'S, NE corner 26S.

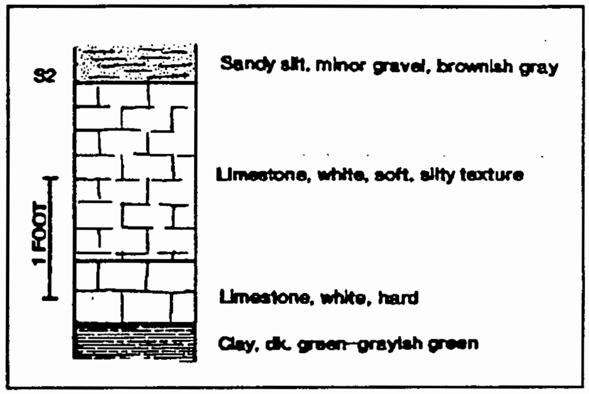


Figure 8b. S2. 130'W, 3460'S, from NE 26S.

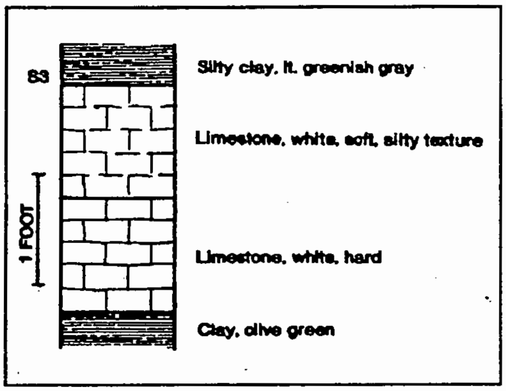


Figure 8c. S3. 1112'E, 2830'S NW 25S.

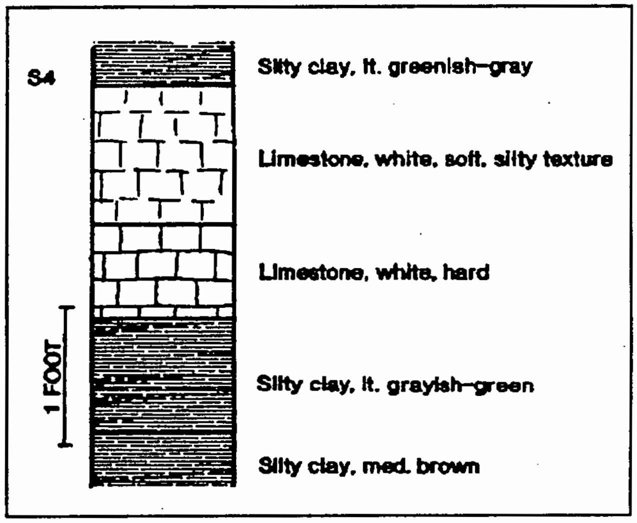


Figure 8d. S4. 1620'E, 4990'S NW 25S.

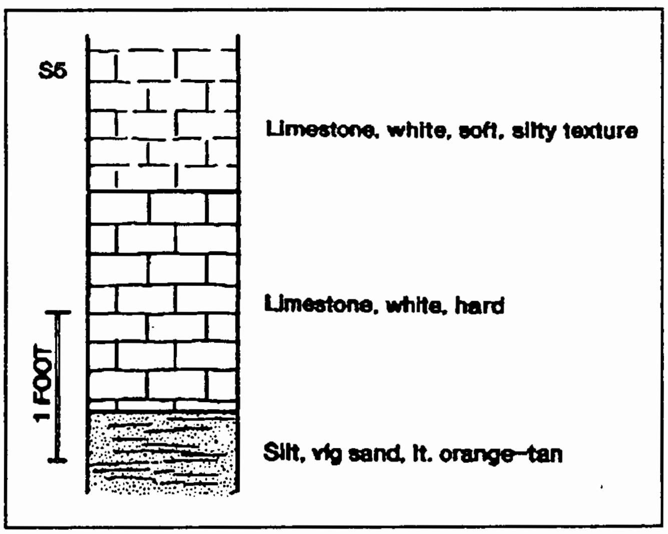


Figure 8e. S5. 500'E, 600'S, NW 26S.

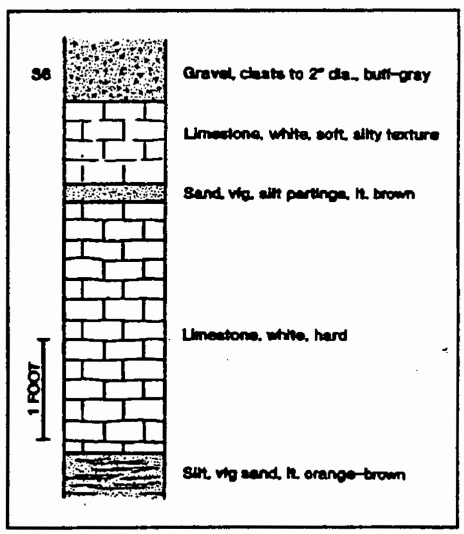


Figure 8f. S6. 2380'W, 1270'S, NE 26S

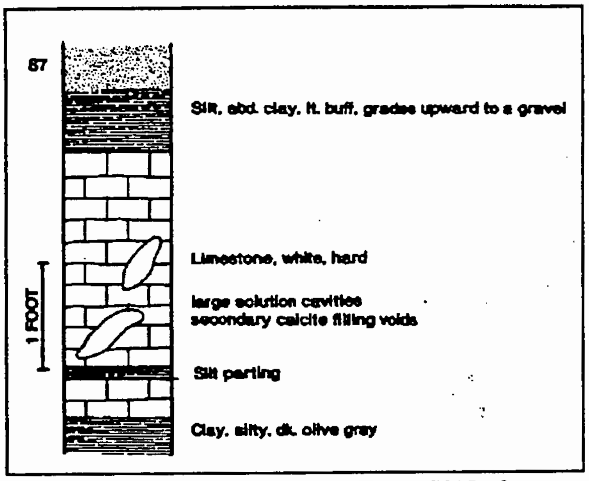


Figure 8g. S7. Location: 1730'W, 1270'S, from NE corner 26S.

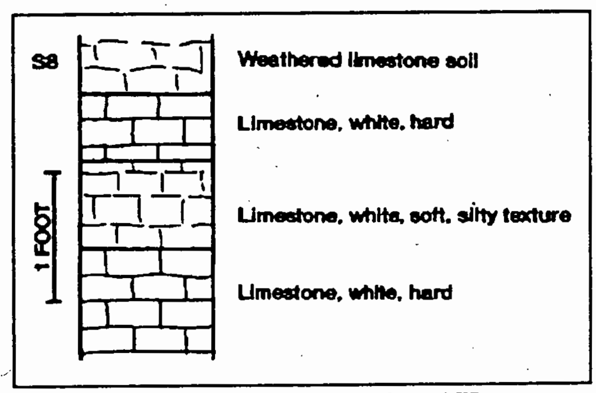


Figure 8h. S8. 2380'W, 1270'S from NE corner 26S.

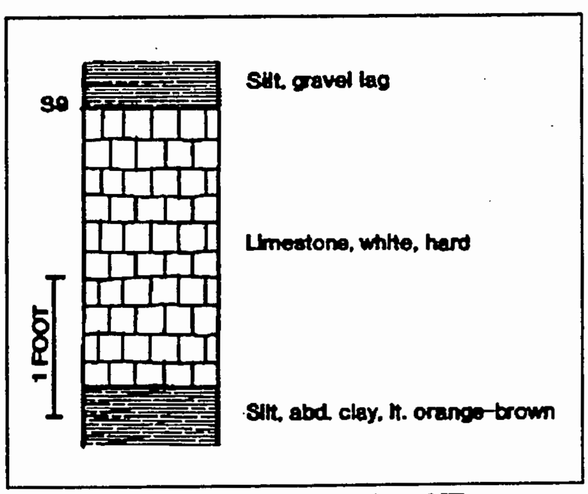


Figure 8i. S9. 1460'W, 1090'S from NE corner 26S.

Gravel and sand were deposited in braided stream channels that migrated laterally, leaving silt and clay overbank and interchannel deposits. Regradational fining upward sequences often culminate in limestones that can be several feet thick (figure 9). Progradational coarsening upward sequences followed as diversion of the stream channel into the shallow lakes resulted in increased sedimentation rates.

Bed thicknesses are proportional to grain sizes within the beds. Within NPR-1, Tulare gravels can be as much as 50 ft thick (Woodring and others, 1932). Within the study area, silts and sands are 5-15 ft thick, and clays generally less than 6 ft. Limestone beds can be as much as three ft thick, but are generally 1-2½ ft thick. Limestones mapped in the study area are commonly less than 20 vertical ft apart, suggesting that thick gravel beds become less common stratigraphically high in the Tulare section.

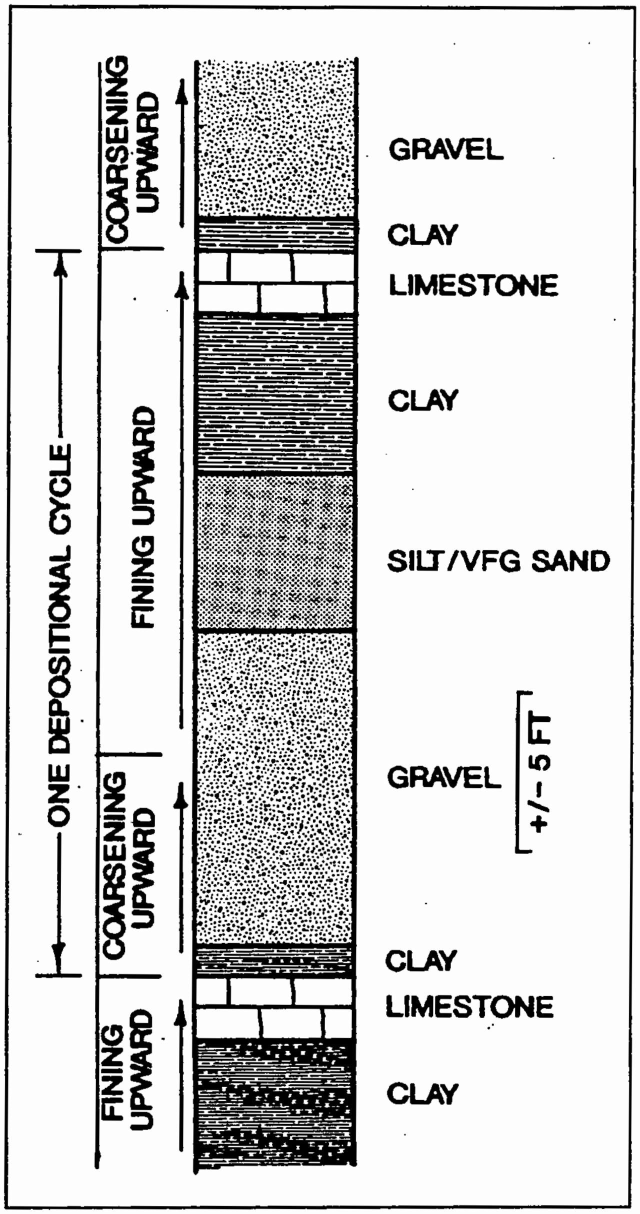


Figure 9. Diagrammatic stratigraphic column showing idealized sequences associated with Tulare channels.

Clays overlying limestones are generally much thinner and have a different color than those that underlie the limestones. These relationships support the idea that the limestones were deposited in shallow, local, and quiet water lakes in topographic depressions between channels. The lack of full coarsening upward sequences (including silts and fine sands) above the limestones may be due to scouring. The absence of limestone at the top of regradational sequences may also be due to scouring by diverted stream channels.

V. Surficial deposits.

Sediments overlying and eroded from the Tulare are mapped as various types of surficial deposits. Surficial deposits on NPR-1 have never been mapped in detail. Woodring and others (1932) show a dashed contact between the Tulare and alluvium. Their definition of alluvium was vague. Over the years, environmental restraints on oilfield activities have emphasized the distinction between Tulare and alluvium, specifically in regards to surface disposal of produced fluids.

In the subsurface, the contact between Tulare and alluvium is less well defined. In the Buena Vista Valley near the southern margin of NPR-1, Milliken (1992) picked an E-log contact at a depth of 470 ft in well Union Oil 1B-20G. Some workers feel that Tulare deposition has been continuous up to present (Tor Nilsen, oral communication, 1993). The age and character of the uppermost Tulare has never been adequately defined. Moreover, the Tulare itself can be described as a thick deposit of alluvium, albeit much older, more widespread, and more disturbed than later "alluvial" (surficial) deposits. The surficial deposits described herein and mapped on plate 1 do not exhibit the same progradational and regradational sequences described for the Tulare above. Bedding attitudes in even the oldest surficial deposit (Qof) do not reflect significant tilting since deposition.

Older fan deposits (Qof). Air photos and topographic maps clearly show the geomorphic expression of an ancient alluvial fan originating in southernmost section 26S and terminating at the distal Kern River fan at Tupman. Termed in this report the Tupman fan (plate 1), it exhibits classical fan-shaped topographic contours and is highly dissected. Later streams have cut down around the edges of the fan and no modern deposition is occurring on the fan's surface (other than local reworking).

To the northwest along the flanks NPR-1, smaller fans of equivalent age to the Tulare fan coalesce into a broad fan apron. Material for these fans was eroded primarily from the crestal area of the Elk Hills structure, where deep erosion has exposed several hundred feet of Tulare rocks. To the southeast, Qof deposits were eroded by the ancestral Kern River and replaced by younger fans.

Older alluvium (Qoa). Modern day stream beds on NPR-1 are commonly cut into older and slightly more extensive stream deposits, here termed Qoa. These deposits exhibit flat surfaces and a diagnostic affinity for cheesebush (*Hymenoclea salsola)* (figure 10).

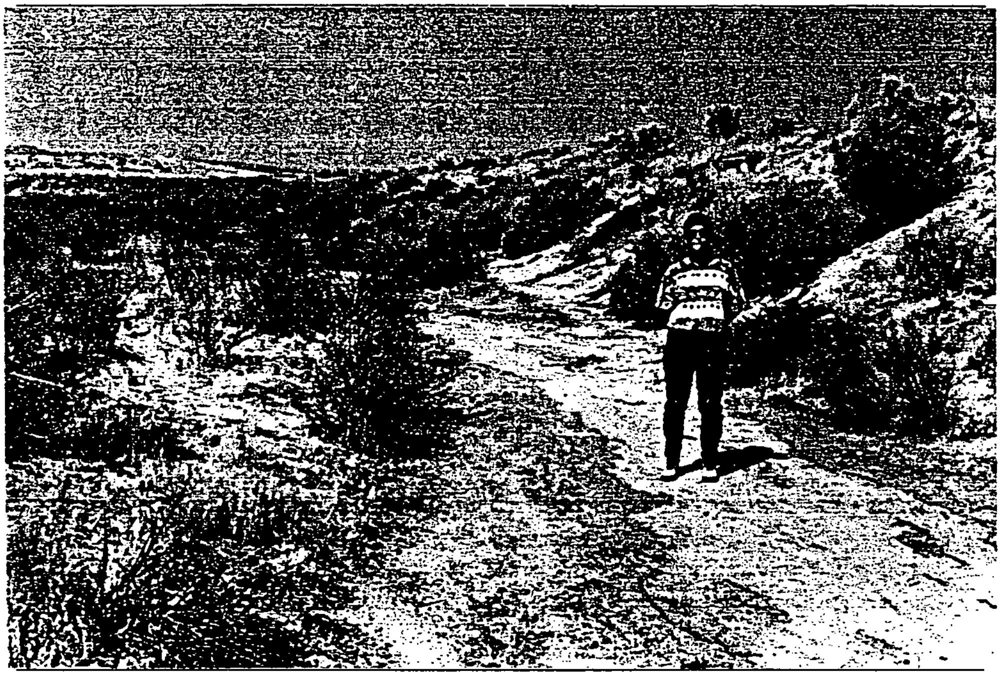


Figure 10. Photo P4. 1500'E, 800'S, NW 25S. Modern drainage with low Qoa terraces on left, and Qof terrace on right. Stream bed is paved with brea.

The concentration of cheesebush on Qoa is a unique character, as the plant appears not to prefer other soils. The vegetation contrast presented by the cheesebush makes Qoa deposits stand out on air photos and in the field. Sand and gravel composing this unit is derived from the Tulare and older fan deposits (Qof). Qoa terraces range in height up to four ft. No faults were seen within this unit.

Flood plain deposits (Qfp). Sediments deposited in this meandering stream environment of the Buena Vista Slough are mapped as Qfp (flood plain deposits) on plate 1. Prior to the Lake Isabella dam and diversion through numerous canals, the Kern River flowed down the Kern River fan to the Buena Vista Slough between Tupman and Buena Vista Lake. Buena Vista Slough is a topographically low area formed where the Kern River fan meets fans and tilted Tulare sediments at Elk Hills. Streams flowing through the slough were meandering, and good examples of typical meandering stream features are seen in stereo-pair air photos. The California Aqueduct now occupies the old meandering stream bottom.

Modern alluvium (Qa). Sediments being deposited by modern streams are mapped as Qa on plate 1. Modern alluvium is primarily limited to small stream channels cut into sediments of the Tulare, Qof, and Qoa. Prior to construction of the California Aqueduct, modern streams emptied onto flood plain deposits of the Buena Vista Slough. Because of the semi-arid climate, small drainage basins, and the lack of intense rain storms, very little modern sediment is being transported down stream channels.

Brea deposits. Brea is a mixture of oil and sand that underlies several modern stream channels within the study area (plate 2). Brea forms a hard pavement-like surface on stream beds that is highly resistant to erosion (figure 10). Most brea within the study area appears to originate at the heads of gullies near old well site locations, particularly the "U" series of wells in SW section 26S and SE section 27S.

The occurrence of brea in stream beds in west side San Joaquin Valley oil fields is common. A study by Jones and Stokes Associates (1989) in Buena Vista, Broad, and Sandy Creeks on NPR-2 concluded that most brea deposits are not hazardous material or harmful to plant and wildlife, and that "..hard brea should remain intact, and no cleanup is required" (p. 5-1). Jones and Stokes determined the biggest hazard to be sticky deposits that entrap animals. During the field inventory conducted for the current study (plate 2), no sticky forms of brea were found. A detailed evaluation report is in preparation, the results of which will determine whether further evaluation would be required.

VI. Rock unit ages.

According to Malcolm Clark (USGS, oral communication, 1993), surficial alluvial sediments in southern California, including Elk Hills, may be tied to periodic fluvial pulses associated with glacio-pluvial climatic episodes of the past 2+ Ma. Rocks of the Tulare and overlying surficial deposits may be related to periods of Pliocene and Pleistocene glacio-pluvial alluviation. A significant amount of fluvial energy was required to move 12 inch metamorphic clasts to Elk Hills from as far away as the San Emigdio Range, 30 miles to the south. Such quantities of water would not be expected during dryer interglacial periods.

Correlation of alluvial units to specific glacial stages is conjectural unless reliable geochronometric controls are available. An age of 1.9-2.4 Ma (specifically 2.2 Ma) was proposed by Repenning (1980) for Limestone A. Fossils were taken from sites originally identified by Woodring and others (1932) and by DOE Geologist Maurice Fishburn. The 2.2 Ma date was based on a spectrum of fossil mammals found stratigraphically near Limestone A and a paleomagnetic reversal found in Limestone A. Repenning (1980) determined the fossil assemblage to represent a warm, wet climate. This age may represent the end of the Nebraskan glacial stage at the Plio-Pleistocene boundary (figure 11a). *(Note: The terms Kansan, Aftonian, and Nebraskan in figure 11a were deemed abandoned by Richmond and Fullerton (1986). The glacial stages were replaced by a series of "pre-Illinoian" glaciations, a concept not yet universally adopted [Richmond, oral communication, 1993]).*

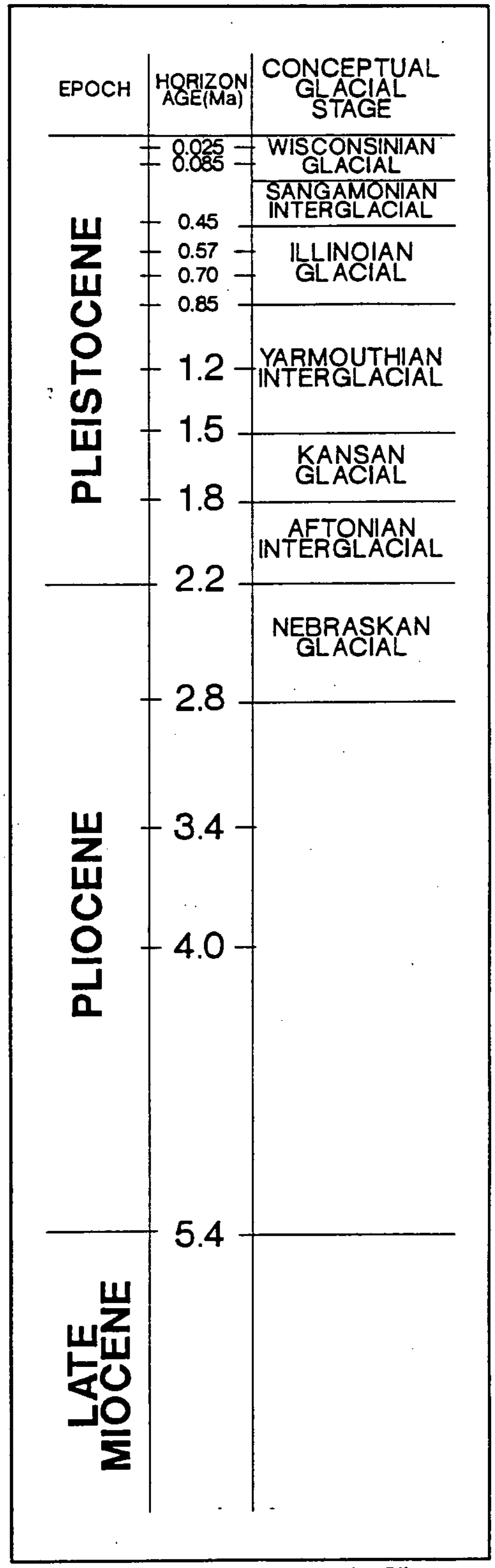


Figure 11a. Geologic time scale showing Plio-Pleistocene glacial stages. From Walters (1993).

Repenning's date of 2.2 Ma is tenuous at best, being based on a fossil assemblage and paleomagnetic polarity that each have broad time constraints. Although not discussed by Repenning (1980), his reversed paleomagnetic sample probably correlates with the Matuyama Reversed Epoch of 0.69-2.43 Ma (figure 11b).

According to Richmond and Fullerton (1986, p. 184): "....A 'date' is derived only if a *polarity reversal* occurs *within* the deposit, and then only if the identity of the reversal can be established." There is insufficient data to judge Limestone A's age relative to the Jaramillo (0.87-0.92 Ma), Olduvai (1.71-1.86 Ma), and Reunion (2.01-2.14 Ma, not shown on figure 11b) normal polarity events within the Matuyama Epoch.

Even if further sampling of other Tulare limestones uncovers a reversal, other more tightly constrained dating criteria will be required to identify the reversal. Given the poor fossil record at Elk Hills, the best hope for accurate age dates may be with so far undiscovered ash beds. Although no ash beds have been reported in the Tulare or surficial deposits at Elk Hills, any of the following wide-ranging ash beds may be present (Sarna-Wojcicki, USGS, oral communication, 1993):

Ash bed	Source Area	Age (Ma)
Lava Creek	Yellowstone	0.67
Bishop ash	Long Valley, CA	0.76
Glass Mtn.	Long Valley	0.70-0.90
Taylor Cyn. 2,3	Long Valley	1.85-2.17
Ishi tuff	S. Cascades	2.20

According to Sarna-Wojcicki, the 2.2 Ma Ishi tuff is found *at the base of the Tulare* in the Kettleman Hills. If Repenning's (1980) date of 2.2 Ma for Limestone A (in the upper part of the Tulare at Elk Hills) is also correct, then the Tulare must be time-transgressive from south to north (Don Miller, Stanford University, oral communication, 1993). In his recent examination of a NPR-1 Tulare core (CH1-27R), Miller found no evidence of volcanic ashes, although much of the section was not cored.

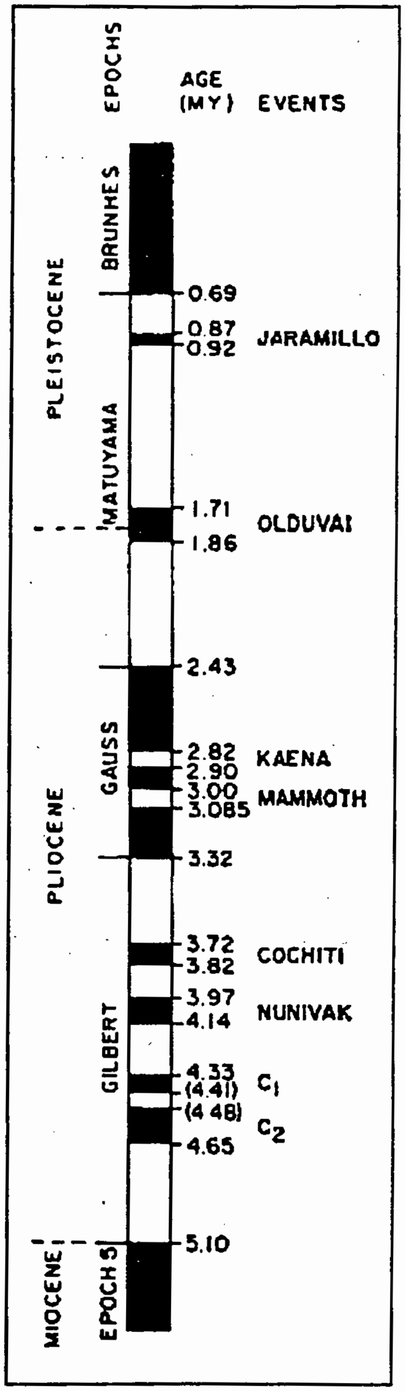


Figure 11b. Normal paleomag intervals are shaded dark. From Stacey (1977).

Tulare deposition may be related to pluvial periods associated with the earliest Tertiary/Quaternary Northern Hemisphere glaciation. This period of glaciation, shown as the "Nebraskan Stage" in figure 11a, began 2.5-2.8 Ma ago in late Pliocene and was at a maximum 2.14 Ma ago (Richmond and Fullerton, 1986). Thus the lower and upper age constraints on the Tulare are 2.8-2.5 Ma and < 2.14 Ma respectively.

The Gauss/Matuyama reversal at 2.43 Ma (figure 11b) is probably in the Tulare at Elk Hills, but so far remains unrecognized. In the Sierra Nevada Range, there is evidence of an alpine glaciation during Tulare time. According to Clark (USGS, oral communication, 1990), the McGee till is to 2.5-3.2 Ma old.A precise date for the end of Tulare deposition at the latitude of Elk Hills is difficult to assess, but is probably within a pre-Illinoian interglacial period between 1-2 Ma ago. Two magnetic reversals associated with the Olduvai event (1.71 and 1.86 Ma) may have occurred near the end of Tulare deposition, or they may postdate the Tulare. Further paleomagnetic work with limestones high in the section (such as those mapped on plate 1) may yield clues.

Older fan sediments (Qof) overlying the Tulare are probably post-Pliocene, although no direct evidence has been found to provide an age. Richmond and Fullerton (1986) discuss Puget Sound ice advances around 1.5 Ma ago, but no time-equivalent glacial deposits have been identified in California. Other evidence strongly suggests a widespread glaciation in California older than the Bishop Tuff (>0.76 Ma) and younger than 1.0 Ma. In the Sierra Nevada Range, the Sherwin Till underlies the Bishop Tuff and probably represents this glaciation. The Bishop ash bed is an important oil field correlation tool in Kern River Fan gravels on the east side of San Joaquin Valley (Don Miller, Stanford University, oral communication, 1993).

The age of the Sherwin glaciation falls within the age brackets of the Illinoian Glacial Stage (figure 11a). Older fan sediments mapped as Qof on plate 1 may be Sherwin in age, based on their superposition to the Tulare. If so, the Bishop ash bed would post-date and overlie Qof. The Bishop ash fall would have covered exposed Tulare rocks and the older fans (Qof), and later eroded and transported off Elk Hills to the San Joaquin Valley. Although an important correlation horizon in the Kern River field (25 miles NE of NPR-1), the Bishop ash bed has not been reported within subsurface or surface rocks of NPR-1 or immediately adjacent areas. Identification of the Bishop ash bed would provide a critical tephrostratigraphic time-marker horizon to date the older fan deposits (Qof).

Stream terrace and fan deposits mapped on plate 1 as Qoa are considerably younger and much less widespread than the older fans (Qof). These sediments may be correlative with one or both glacial advances recorded in California of Wisconsin age. In the Sierra Nevada Range, late and early Wisconsin alpine glaciations range in age from 10,000 years (Tioga glaciation) to 130,000 years (Tahoe glaciation).

There are no known time-stratigraphic horizons in Southern San Joaquin Valley that would be useful in dating beds mapped as Qoa. Further examination of exposed Qoa sediments in stream beds may yield a paleosol suggesting an interglacial period between late and early Wisconsin.

VII. Structural geology.

The study area lies on the gently dipping northeast flank of the eastern Elk Hills anticlinal structure. This broad structure elevates the Tulare between 200-300 ft at the crest of the anticline. Structural relief increases with depth, with dips in excess of 45° in Miocene and older rocks. Within the study area, dips of Tulare beds generally range between 3° and 7° to the northeast. Faults are apparent on air photos, but offsets are difficult to measure due to poor exposures and a lack of subsurface data.

Folding. Folds in the Tulare on NPR-1 have been mapped in the past (Woodring and others, 1932), but their origin has never been adequately explained. One Tulare fold on the south flank of NPR-1 was unsuccessfully drilled for oil potential in the 1940s (well 46-11B). Tulare folds may have relatively shallow detachments (Milliken, 1992) and may be related to gravity flowage. Woodring and others (1932), however, questioned gravity origins for folding because of the gentle slopes on which the folds reside. Moreover, Woodring's geologic map shows folds on the south flank of NPR-1 to be aligned along a left-stepping en-echelon pattern.

Woodring and others (1932) did not map surface folds within the current study area. Several small-scale folds are present and were mapped for this current report. A series of short, tight folds in the N½ of section 26S appears to be fault-related, although the faults are not readily apparent on the ground. Bedding plane measurements on limestone tops yield dips as much as 19° (figure 6). Fold axes trend to the north and slightly west of north. The fold axes are aligned 40° to 45° oblique to the general northwest strike of Tulare rocks. If gravity was responsible for these folds, their axes would be expected to align with the strike (perpendicular to dip) of Tulare bedding.

Small anticlines commonly form ridges with adjacent synclines as drainages. The amount of structural relief in these folds is less than 50 ft, and their cross-sectional forms are poorly exposed. The folds mapped in plate 1 were identified by strike and dip orientations measured from outcrops. Folds mapped in section 25S are much broader and less extensive than those in 26S. No folding was seen in rock units younger than the Tulare.

Faulting. Woodring and others (1932, their plate 1) showed as uncertain northeast-trending faults 2 and 3 passing through the study area within the two largest drainages. Woodring showed these as major faults offsetting the Tulare about 75 vertical feet in section 35S to the south and southwest of the study area.

The drainages in which Woodring and others (1932) projected their possible faults are visible in LANDSAT imagery as curvilinear features that reach to the crest of the Elk Hills structure in sections 2G and 3G. These faults, however, do not offset surficial deposits within the study area. To estimate their throw, two structural cross sections were drawn between wells to the south of the study area in section 35S. These cross sections are A-A' (figure 12) and B-B' (figure 13). The cross sections are based on a series of wells oriented roughly perpendicular to fault strike and parallel to bedding strike. Correlations were made with units within the Tulare, San Joaquin, and the Shallow Oil Zone (SOZ, Etchegoin). The deepest correlation marker used is the SS1 (Sub Scalez) sand. Correlations show these faults to sole out in the Miocene Reef Ridge Shale (Maher and others, 1975).

Cross section A-A' (figure 12) is across fault 2 of Woodring and others (1932). At a subsea elevation of -2000 ft, the fault demonstrates about 400 ft of dip-slip offset in the IV Mya sand. At shallower depths, the fault appears to bifurcate into an eastern subparallel branch. There is a curvilinear erosion pattern on the surface where the subsidiary fault is projected to the surface. Throw along these faults seems to lessen with shallower depth. Based on these cross sections, 200-250 ft of throw is projected for fault 2. The subsidiary fault probably has less than 80 ft of throw at the surface.

Cross section B-B' (figure 13) demonstrates structural relationships across fault 3 of Woodring and others (1932). At a subsea elevation of -2000 ft, the SS1 sand is offset 368 ft of dip slip. The throw is 300 ft in the lower part of the Tulare at an elevation of sea level. At the surface, dip slip along fault 3 is probably 250-300 ft.

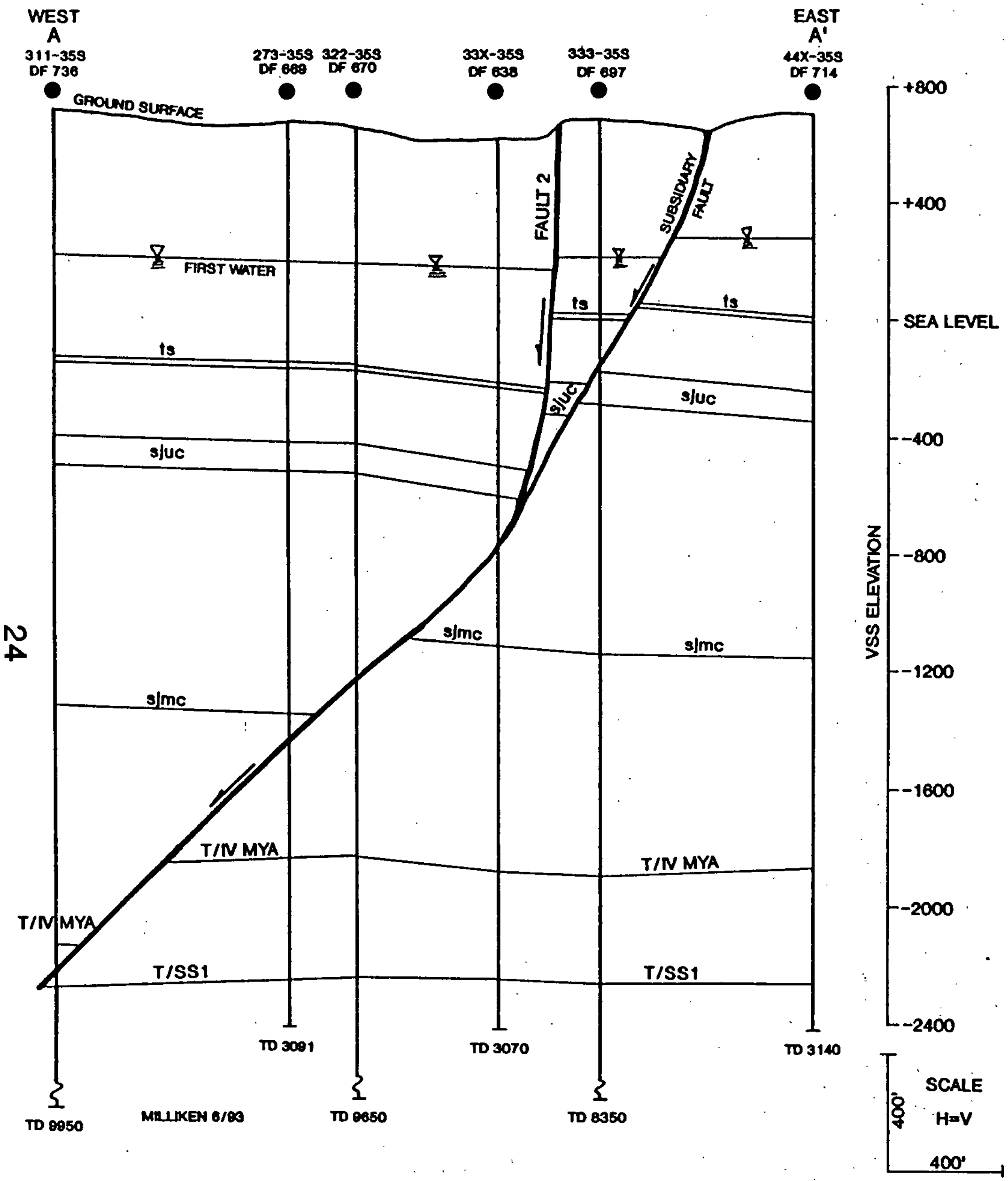
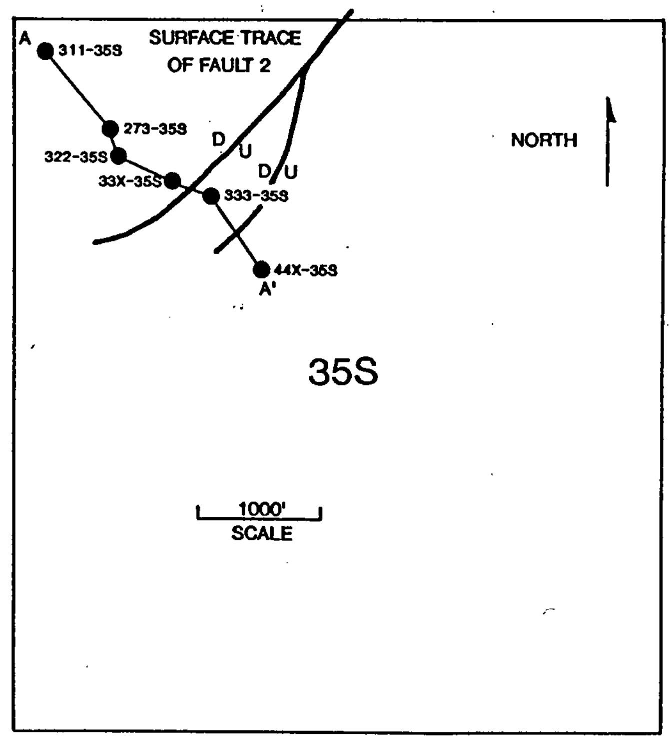


FIGURE 12.
STRUCTURAL CROSS SECTION SHOWING SUBSURFACE EXTENSION OF "FAULT 2" OF WOODRING AND OTHERS (1932)

EXPLANATION: ts: unnamed sand of lower Tulare Fm.
sjuc: uppermost clay zone of the San Joaquin Fm.
sjmc: correlation point of mid-San Joaquin Fm.



LOCATION MAP

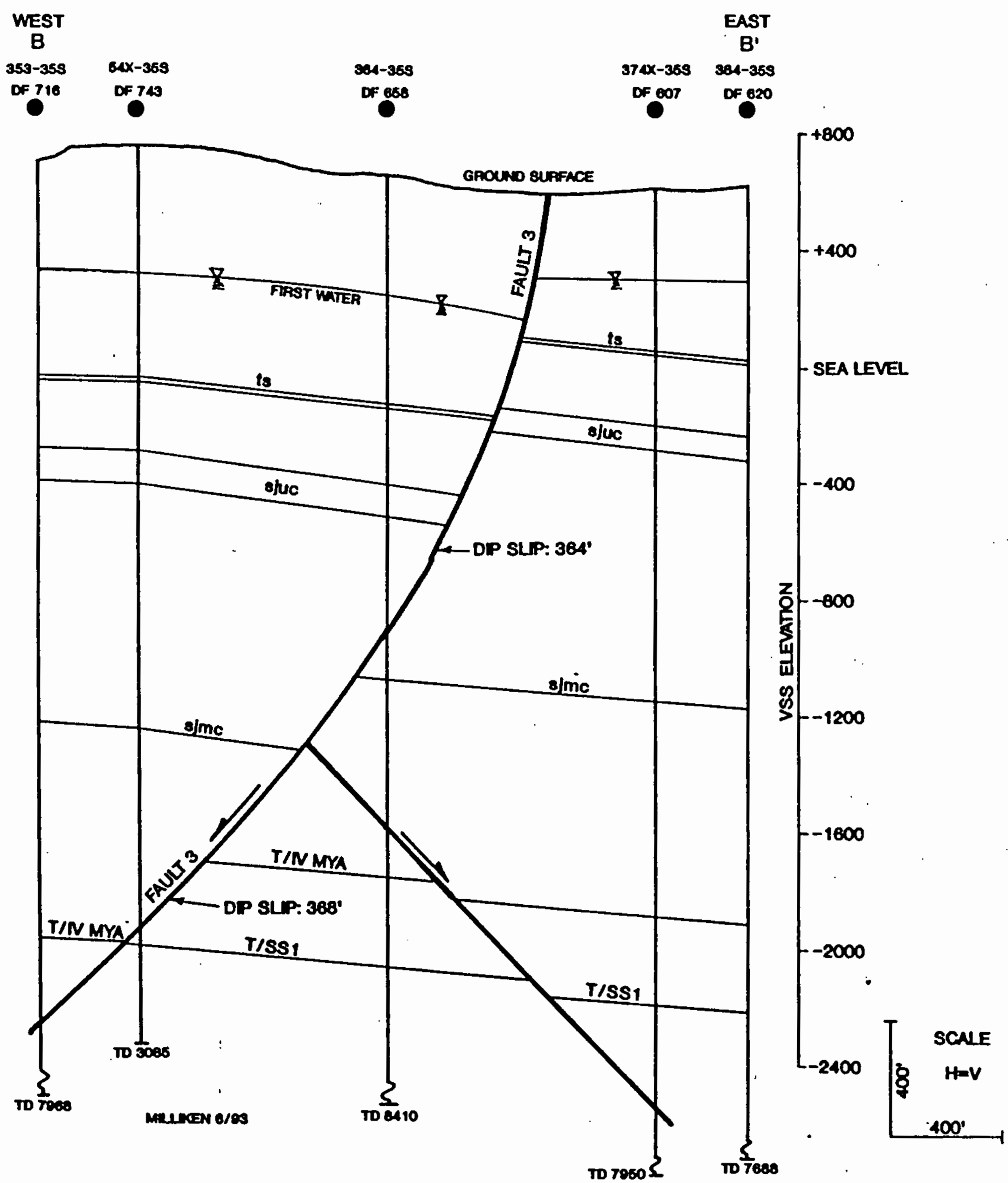
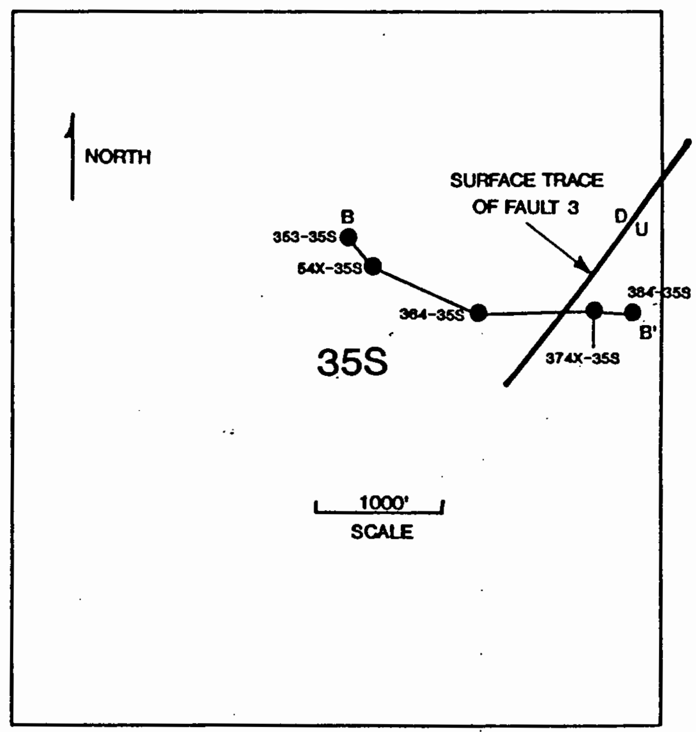


FIGURE 13.
STRUCTURAL CROSS SECTION SHOWING
SUBSURFACE EXTENSION OF "FAULT 3"
OF WOODRING AND OTHERS (1932)

EXPLANATION: ts: unnamed sand of lower Tulare Fm.
sjuc: uppermost clay zone of the San Joaquin Fm.
sjmc: correlation point of mid-San Joaquin Fm.



LOCATION MAP

Most of the upthrown blocks between faults 2 and 3 have been eroded away, so surface correlations are difficult. The amount of transform movement, if any, is unknown. The folds discussed above in sections 25S and 26S may be related to wrenching between these faults and possibly Woodring's fault 1 in section 27S immediately west of the study area.

If laterally continuous, fault 3 of Woodring and others (1932) would extend along strike into the 25S LACT site. Indeed, wells 361-25S and 382-25S are perfectly positioned to have the fault pass directly between them. Structural cross section C-C' (figure 14) was prepared between the two wells to confirm the presence of fault 3. Both wells appear to be cut by a westward-dipping normal fault with 140 ft of dip-slip displacement. But no fault appears to cut the uppermost Tulare *between* wells 361-25S and 382-25S as would be expected with Woodring's fault 3.

Smaller faults noted in well 382-25S may be splays from a larger fault. Cumulative dip slip from the three faults noted in well 382-25S (figure 14) is about 230 ft. This amount of slip is close to that identified for fault 3 in section 35S (250-300 ft). But the fault locations projected to the surface are ¼-½ mile southeast of the projected trend of fault 3 by Woodring and others (1932). A fault mapped on the surface (plate 1) aligns nicely with the projected surface location of the larger (140 ft) fault cutting well 382-25S (figure 14). This surface fault, however, appears from surface relationships to have only a few tens of feet of vertical displacement.

There may be a northwest-trending strike slip fault or family of faults along the northern flank of NPR-1 (see discussion on the Tupman Fault below). If such faults exist, the subsurface extensions of Woodring's northeast-trending normal faults would be laterally offset. There is no surficial evidence of a major strike slip fault in this vicinity. The question remains regarding the disposition of the northeast extension of Woodring's fault 3. This is an important aspect of the geology and geohydrology within the study area, for faults in the Tulare have profound effects on groundwater distribution at Elk Hills.

Tupman Fault. A spectacular northwest-trending fault trace is exposed on the surface of the Tupman fan and other fans to the west and northwest of the Town of Tupman (plate 1). This fault is one of a family of northwest-trending *en-echelon* faults within the Tulare and fans that bound the northern margin of the Elk Hills structure.

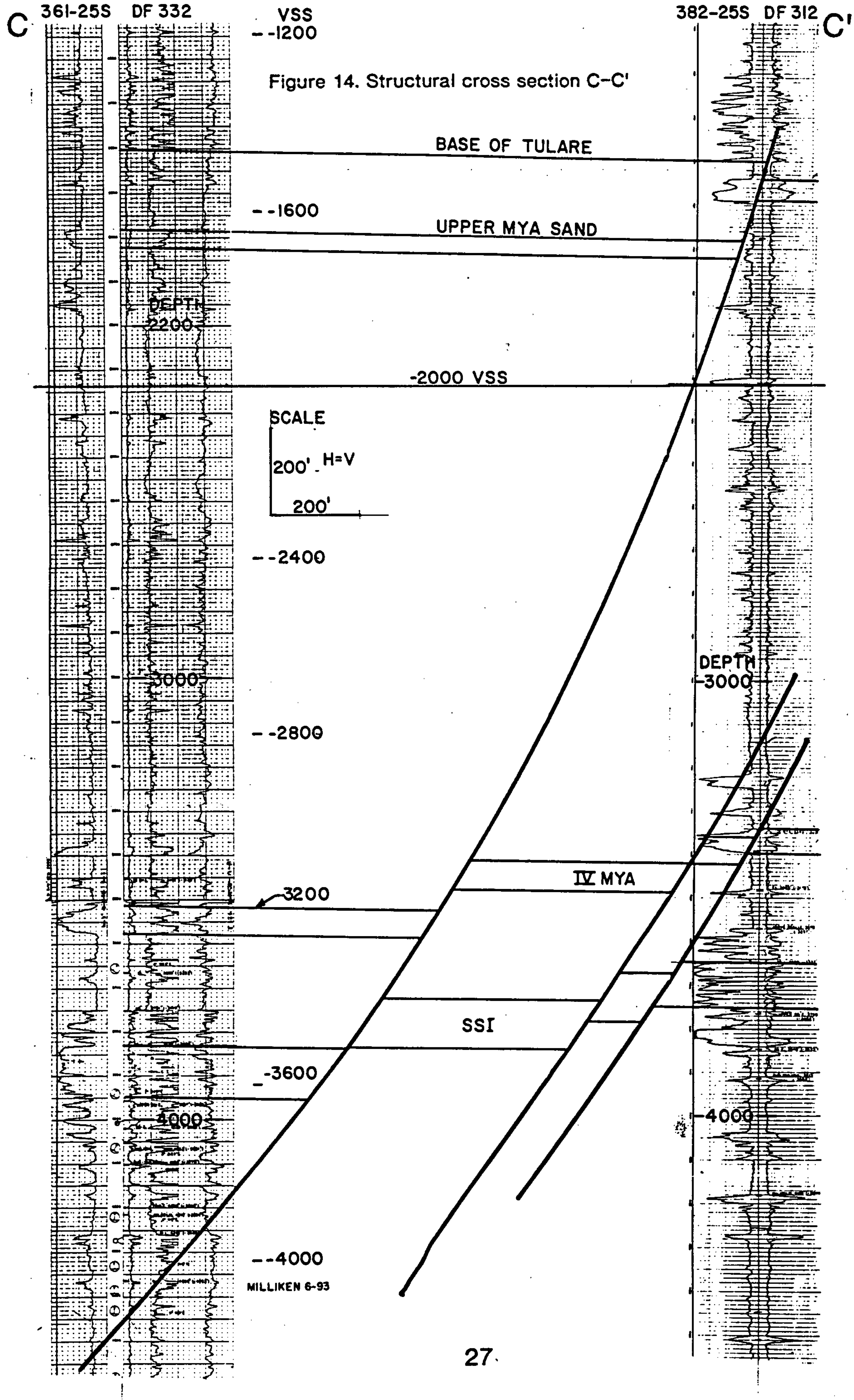


Figure 14. Structural cross section C-C'

Woodring and others (1932) mapped these features as "earthquake cracks." Maher and others (1975), in their republication of Woodring's geologic map, did not reference the "earthquake cracks," or map them.

A careful study of the Tupman Fault on stereo pair air photos shows an exposed length of 4200 ft. Evidence for strike slip displacement is subtle, but offset gullies suggest about 11 ft of left-lateral offset. Although difficult to quantify, vertical movement is suggested by several factors. In air photos, the northern block is topographically and structurally higher than the southern block across the fault. The fault scarp is deeply eroded, but topographic highs to the north of the fault suggest at least five to ten feet of uplift. Moreover, gullies in the Tupman area are deeply incised north of the fault, suggesting uplift and rejuvenation of the northern block (plate 1). The youngest sediments cut by the Tupman Fault are fan deposits of Qof (plate 1). Terrace gravels mapped as Qoa are not offset by the fault.

Other faults in the Tulare. An arcuate fault exposed on the ridge directly west of fault 3 of Woodring and others (1932) in the middle of section 25S displays its scarp geometry well in the field (figure 15). The fault trace is spectacularly exposed in the field and air photos.

Figure 15. Photo P6. Northward dipping fault plane near the center of section 25S. The fault plane dips 53° north (left in photo). Movement may be reverse.

A dip of 53° to the north is easily measured, although the sense of movement is not clear. In air photos, the northern block (footwall) of the fault appears to be upthrown, suggesting reverse movement. Alternatively, the arcuate trace of this and a similar fault to the southeast on the next ridge suggest low-angle gravity slump scarps.

Faults in northernmost section 26S are very poorly exposed in the field, and their traces are based primarily on air photo interpretation. The 26S faults seem to be associated with tightly folded rocks of the Tulare (plate 1). Limestone exposures often appear to terminate at faults, suggesting vertical displacement. Amounts of displacement were not be determined because of poor exposures and problems involved with limestone correlations. Most of these faults cut only the Tulare, although some appear to continue into older fan deposits (Qof) of the Tupman fan.

As mentioned earlier, faults and folds in the northern part of section 26S may be related to wrenching tectonic forces between faults 1 and 2 of Woodring and others (1932). Alternatively, the structures may be transpressional features associated with pre-Qof strike-slip displacement of the Tupman Fault. The latest movement of the Tupman Fault, however, produced no known folding in the older fan (Qof) deposits.

Angular unconformity. Anomalous structural relationships exist among beds along the ridge in extreme eastern section 25S. Limestones and gypsum-cemented sandstones on the flanks of the ridge dip 7° to the northeast. Capping the ridge is an erosional unconformity and a thin limestone dipping 3° also to the northeast. This relationship may represent an angular unconformity. If so, the unconformity is not readily recognized in other areas.

VIII. Groundwater implications.

Groundwater distribution in the study area is difficult to assess because of a lack of shallow subsurface data. Golder Associates (1990) prepared a groundwater elevation map that was later updated and corrected by Tom Mele of BPOI (Phillips, 1992). Mele's map shows a groundwater elevation of 200 ft in sections 25S and 26S, and 150 ft in the area north of the California aqueduct.

Tulare groundwater quality is generally poor, with TDS concentrations commonly exceeding 5000 ppm (Phillips, 1992). There are no natural springs within the study area, although Golder Associates (1990) reported springs related to pipeline leaks. An apparent groundwater mound along the axis of the Elk Hills structure has led some investigators to conclude that groundwater is flowing from Elk Hills to adjoining basins (Rector, 1983). Several factors dispute that notion.

The relatively high salinity of Tulare water suggests a connate origin. Groundwater flow off the flanks of the structure would require significant recharge along the crest of Elk Hills and discharge in the adjoining valleys, neither of which is occurring. Poor groundwater quality of the Tulare combined with a semiarid climate suggest little or no recharge and flushing of water-bearing strata is occurring. Produced groundwater in the San Joaquin Valley to the north and east of the study area is of better quality than Tulare water beneath Elk Hills, and is probably sourced from shallower gravels of the Kern River fan.

Faults 2 and 3 of Woodring and others (1932) clearly form groundwater barriers. Indeed, the groundwater levels may have been displaced vertically along with their containing strata (figures 12 and 13). Other faults may cause elevation of groundwater surfaces, aiding the impression of mounding. Tom Mele of BPOI (oral communication, 1993) states that faults do control groundwater elevations at NPR-1, but such detailed analyses were beyond the scope of his work (Phillips, 1992) and that of Golder Associates (1990) in the preparation of small scale groundwater elevation maps. Based on comparative data from section 35S, other faults in the study area (including the Tupman Fault) may be groundwater barriers as well.

Other possible causes for the groundwater mound on NPR-1 may be related to Tulare lithology or folding. Mark McCullogh of BPOI prepared sample paddles from cuttings of Tulare source wells on the south flank of NPR-1. He found that the Tulare decreases in grain size with depth. Lower permeability rocks at the core of the Elk Hills anticline could have high capillary pressures relative to coarser grain rocks higher in the section, causing a capillary rise in groundwater along the anticlinal axis.

The most likely explanation of the groundwater mound involves the uplift of Tulare connate water along with its containing strata. The Tulare consists of alternating gravels, sands, silts, and clays. The clays are very clean and are barriers to the vertical migration of groundwater (Bean and Logan, 1983). As uplift of Elk Hills continued in a broad fold, groundwater migration was restricted across dipping clay beds, leaving water "stranded" high on the structure. Whatever the explanation for the groundwater mound, there is no evidence to suggest that Tulare water is flowing off the Elk Hills structure to surrounding basins.

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NAVAL PETROLEUM RESERVES IN CALIFORNIA

TECHNICAL REPORT

ANALYSIS OF SURFACE FRACTURES ASSOCIATED WITH DISPOSED WATER BREAKOUT OF WELL 58WD-7G, 10/23/93

By
Mark Milliken
DOE Staff Geologist

November, 1993

ANALYSIS OF SURFACE FRACTURES
ASSOCIATED WITH DISPOSED WATER
BREAKOUT OF WELL 58WD-7G, 10/23/93

Summary and conclusions. On October 23, 1993, produced water being injected into the Tulare Formation broke through to the surface at a location about 1060 ft northeast of well 58WD-7G. A field investigation on Monday, October 25 uncovered a pattern of fractures on the surface along a linear zone trending N. 18° E. from the well. Careful examination of the fractures shows they tend to increase in age southward from the breakout. The trend of the fracture zone is similar to linear trends within exposed Tulare rocks. The surface fractures were probably caused by reservoir pressures that exceeded the fracture gradient for the Tulare. The fractures apparently propagated from south to north over a period of several weeks, culminating in flow to the surface at a topographically low area.

Background. Produced water was discovered flowing from erosional depressions on the surface northeast of well 58WD-7G at about 6 PM on Saturday, October 23, 1993. There was some initial confusion about which well was responsible, and about 24 additional hours went by before 58WD-7G was shut off and flow stopped. BPOI estimates a total loss of about 10,000 bbls of produced water. The spill was limited to small drainages flowing into the larger creek bed near the road. Water flowed along only about 400 ft of the drainages, suggesting the spill was less than 10,000 bbls, or that the water quickly percolated into the ground.

On October 25, a field party consisting of Tony Reid, Harvey Deutsch, and myself visited the location. Several fresh fractures were noted around the breakout vicinity. The fractures continue to the southwest, aligned along a northeast-southwest trending zone. The fractures stop on a ridge about 500 ft southeast of the breakouts. On the ridge near hill 786.97, the alignment of the fracture zone with well 58WD-7G became obvious. On October 26, I made a follow-up visit to photograph the fractures and take detailed notes. The fractures showed evidence of different ages, and they were oriented oblique to the general trend of the fracture zone. Rough locations of the fracture zone and breakouts were triangulated using a Brunton compass. The approximate location of the largest breakout is 1060 ft from well 58WD-7G on a bearing of N. 18° E. (figure 1). The breakout coordinates are roughly 1370' N., 1883' W. of the SE corner, section 7G.

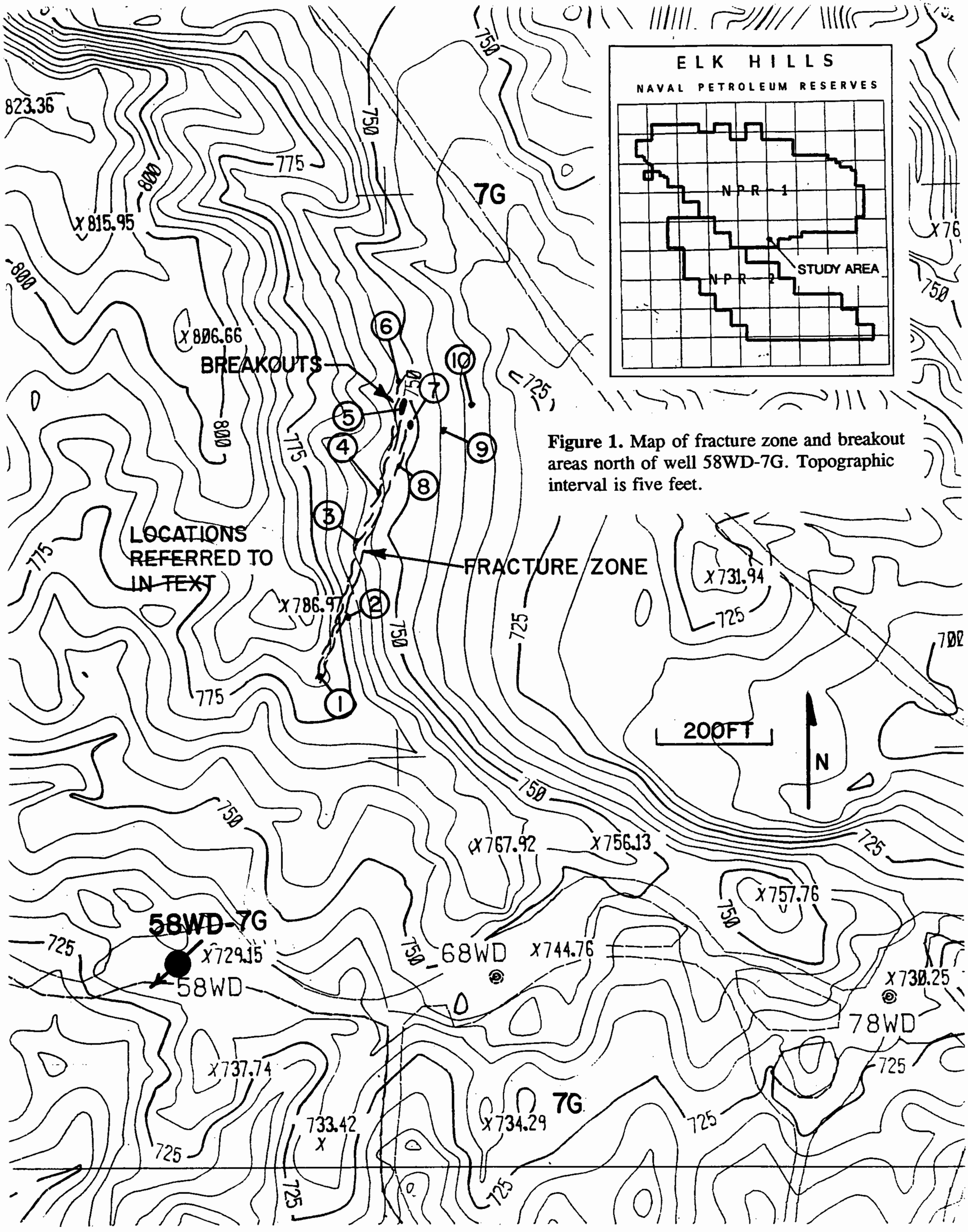

Figure 1. Map of fracture zone and breakout areas north of well 58WD-7G. Topographic interval is five feet.

Fracture timing. The fractures appear to be oldest at the southern end of the fracture zone. The youngest fractures are in the immediate vicinity of the breakouts. This relationship suggests that fractures propagated south to north, culminating in water to the surface at a topographically low spot. The older fractures are on the order of weeks older than the youngest, suggesting that the fractures propagated over a period of weeks before surface flow began. Very fresh fractures near the breakouts probably formed within days or concurrent with surface flow.

The criteria for determining relative ages of fractures are:

1. **Width of fractures.** Older fractures are generally wider, some exceeding 0.5". Younger fractures commonly do not exceed 0.1" in width.

2. **Sharpness of fracture edges.** The edges of older fractures are weathered and rounded, while younger fractures are sharp and well-defined.

3. **Fill material.** The older fractures are commonly filled or overlain by plant, soil, and rock debris moved primarily by animal activity. Younger fractures are generally clean and often cut through recent animal excavations.

Fracture orientation. The fractures occur in a left-stepping *en-echelon* pattern along a 10 ft wide zone. The zone is about 500 ft long and begins 560 ft northeast of well 58WD-7G (figure 1). The fracture zone strikes N. 18° E., and the fractures are oriented ±20° obliquely to the east. Fracture trends range from N. 20° E. to N. 55° E., with the strongest trend being between N. 30°-50° E. (figure 2). Some fractures are oriented to the NW and may not be associated with the subject fracture zone.

Cause of fracturing. The fracturing is clearly related to the release of disposed water at the surface. The surface disturbance may be an extension of a pre-existing fracture at depth reactivated by increased injection pressure in Tulare rocks. No lineament analysis was done within the area surrounding the fracture zone. Airphotos do show weakly developed NE trends in drainages and photo-linears, although there is no specific indication of surface jointing coincident with subject fracture zone. The strongly developed left-stepping *en-echelon* fracture fabric suggests right-lateral wrenching may be involved.

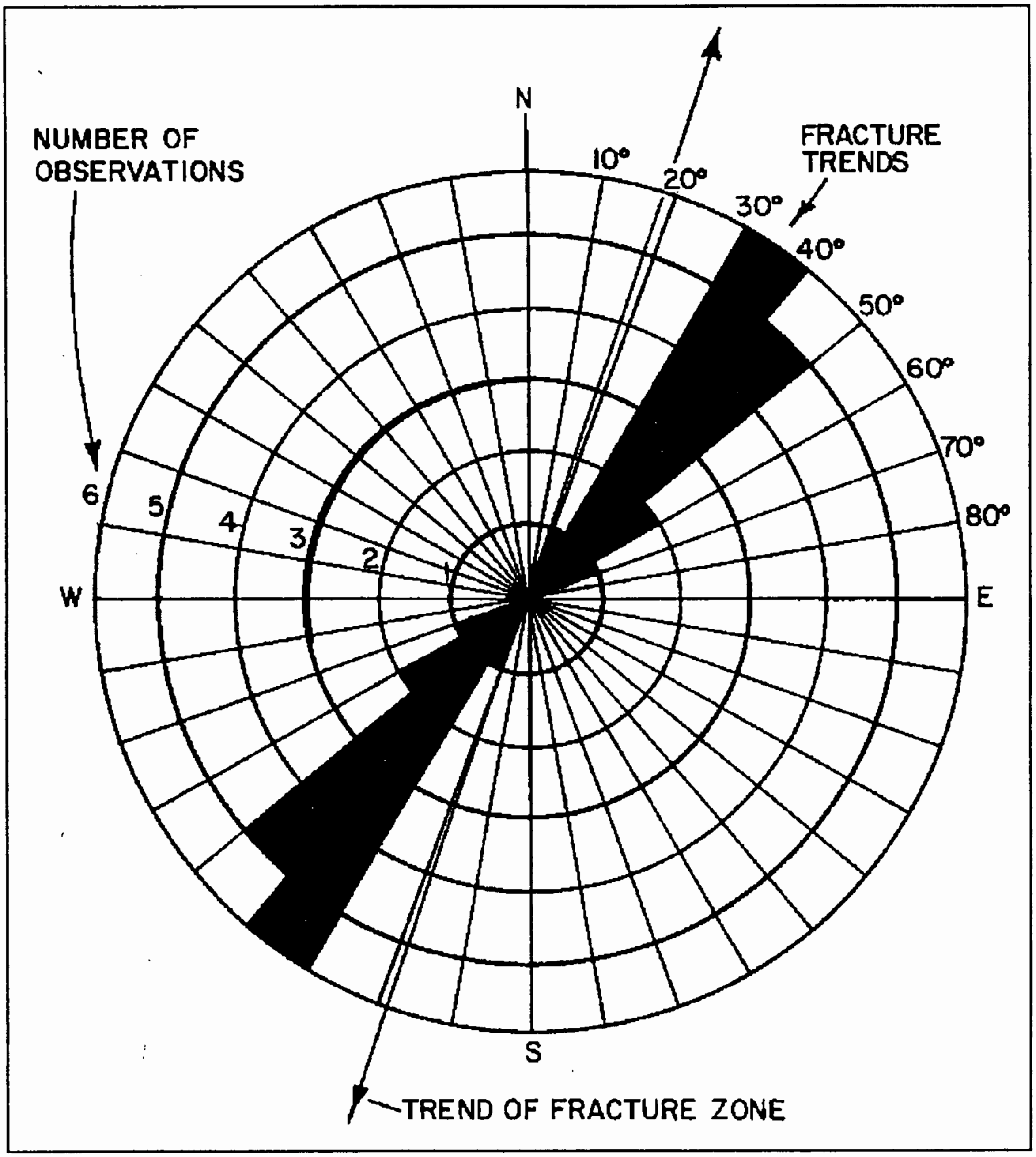

Figure 2. Rose diagram of fracture trends. Note how the fracture trends are shifted 20° east from the trend of the fracture zone.

During the field investigation of 10/26/93, notes and photos were taken at ten locations on and adjacent to the fracture zone to record fracture characteristics. These locations are identified as 1 through 10 on figure 1. Observations made at each location are discussed below.

Location 1. This is the farthest south the fractures are exposed. The fractures here are the oldest, as suggested by their degree of burial (figure 3). Fracture widths are 0.10-0.15 in, and strikes are between N. 35°-60° E.

Figure 3. Location 1: partially buried fracture at south end of fracture zone. This fracture may be several weeks old.

The *en-echelon* fabric of the fractures is best illustrated at location 1. Figure 4 is a map of fractures at this location drawn to scale. Although widely spaced, the fractures are oriented about 20° oblique to the fracture zone. On figure 4 is a theoretical shear couple strain ellipse showing axes of maximum (a-a) and minimum strain (c-c). Tension cracks form perpendicular to the axis of greatest strain, a-a, and parallel to the axis of least strain, c-c. If the *en-echelon* fracture pattern is due to a shear coupling, the mechanism may be differential pressure loading along Tulare blocks separated by a pre-existing fracture trending radially from well 58WD-7G.

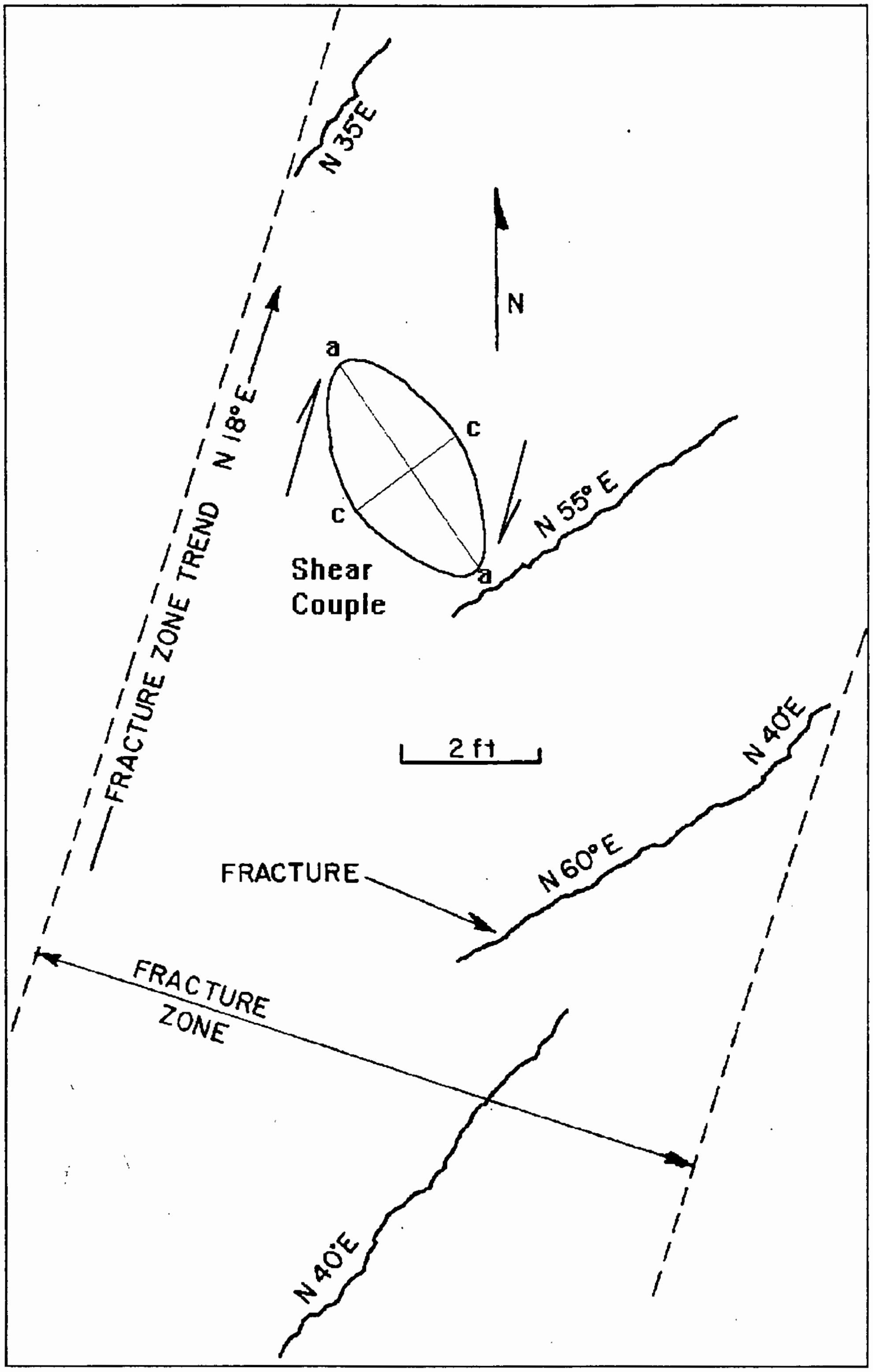

Figure 4. Map to scale of fractures at the south end of the fracture zone (location 1 on figure 1). The *en-echelon* pattern may be due to a shear coupling.

Location 2. This location is about 100 ft NE of location 1 (figure 1). The fractures here are up to 0.30 in wide, and are partially covered. The edges of the fractures are sharper than at location 1, and the openings are not covered to the same degree. Fractures here are *en-echelon* and trend N. 55° E. Although these fractures are apparently younger than at location 1, they are still weeks old.

Location 3. This location is about 250 ft NE of location 1. Young *En-echelon* fractures strike N. 35° E., and are spaced about four feet apart. The fracture openings are small (<0.10 in) and have fresh edges, suggesting an age on the order of hours or days (figure 5).

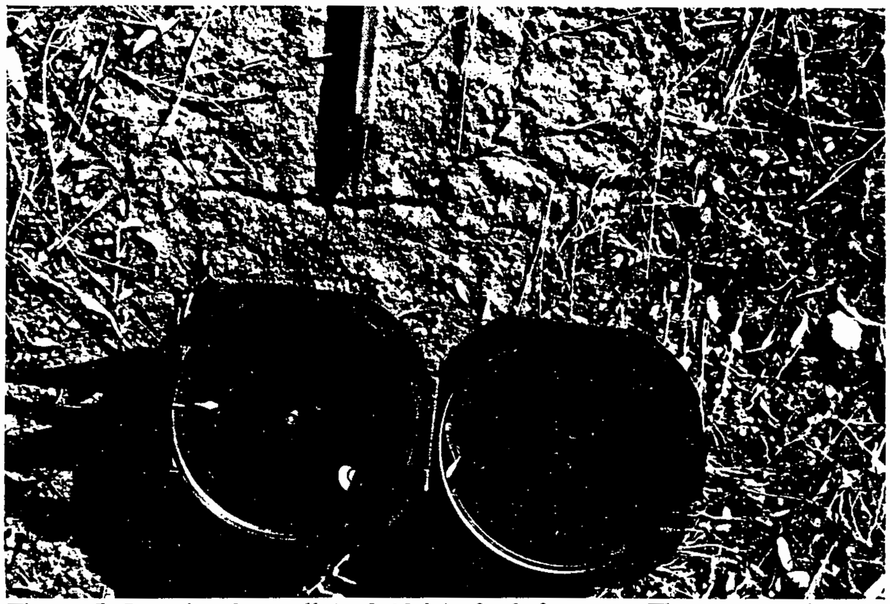

Figure 5. Location 3: small (<0.10 in), fresh fractures. These are on the order of hours or days old.

Location 4. This location is about 350 ft NE of location 1. Microfracture openings are small (<0.10 in) and very fresh, and are similar to those at location 3. The fractures strike N. 30°-47° E.

Location 5. Site of the main breakout. Water flowed from two adjacent sources oriented along strike of the main fracture zone. The erosional depression is seven ft long, 1½ ft wide, and three ft deep (figure 6). Several very fresh fractures are associated with this depression, many of which were obliterated by flowing water. Associated fractures were concurrent with the breakout. They are up to ½ in wide, and trend roughly along N. 40° E.

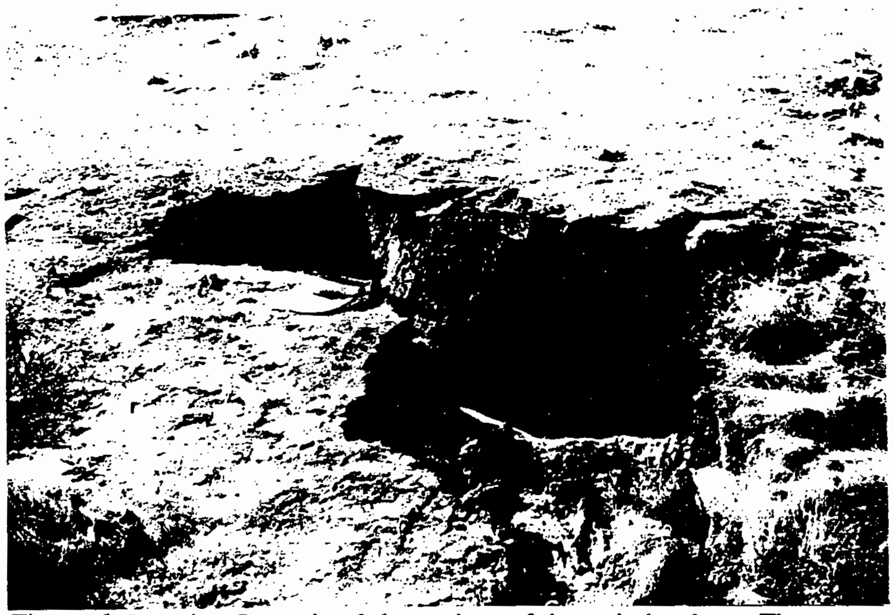

Figure 6. Location 5: erosional depressions of the main breakout. These are about 1060 ft NE of well 58WD-7G.

Location 6. Location is about 20 ft north of the main breakout depressions at location 5. Here, two five ft *en-echelon* fractures are separated by less than one foot (figure 7). The fractures are 0.50 in wide and strike N. 40° E. No microfractures are present, and the cracks are partially buried, suggesting an age of several days or weeks.

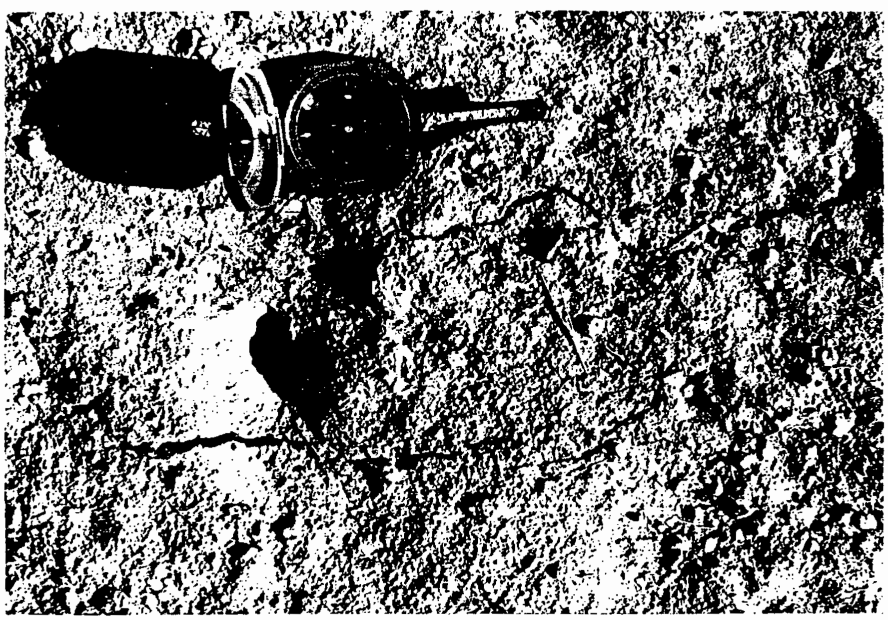

Figure 7. Location 6: *En-echelon* fractures that extend about 20 ft beyond the breakout depressions at location 5.

Location 7. Smaller breakout depressions occur about 20 ft SE of the main breakout (location 5). Several microfractures (<0.10 in) trend N. 45° W. and N. 80° W. These trends are oriented about 90° to most other fractures associated with this zone. The breakout depression itself is along a large, fresh fracture striking N. 35° E. (figure 8).

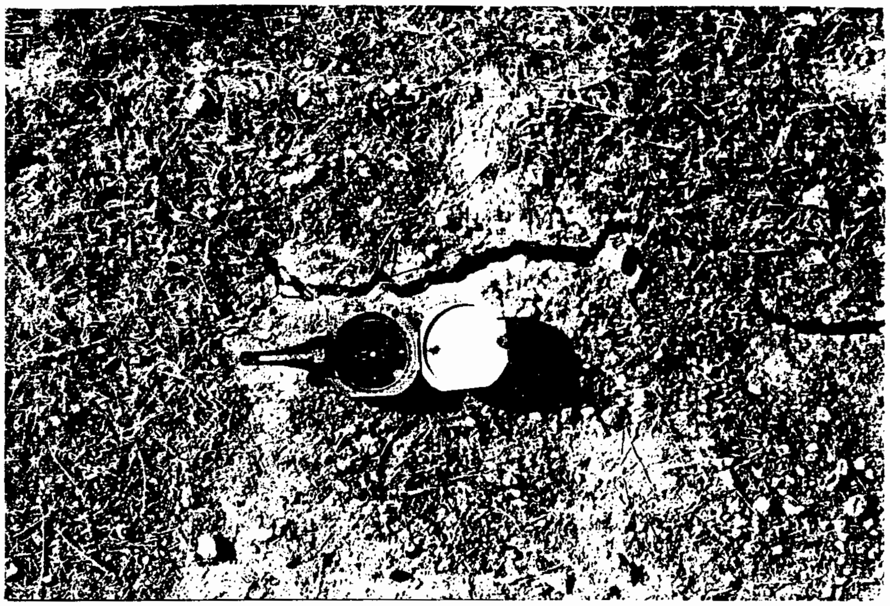

Figure 8. Location 7: fracture striking N. 35° E. that terminates in the secondary breakout depressions, SE of location 5.

Location 8. An older fracture here strikes N. 40° E. and terminates near the secondary breakout depressions at location 7. The fracture is very wide (0.60 in) and is 20-30 ft long.

Location 9. Fractures at locations 9 and 10 appear to be unrelated to the main fracture zone, both in location and orientation (figure 1). An older fracture at location 9 is about 0.10-0.20 in wide, 2-3 ft long, and strikes N. 80° W. (figure 9).

Location 10. This location is about 120 ft east of the main breakout depressions (location 5). Here, a very short fracture terminates in an animal burrow. This older fracture is < 2 ft long, is 0.10-0.20 in wide, and strikes N. 35° W. (figure 10).

Figure 9. Location 9: older fracture SE of main fracture zone. Unusual strike is N. 80° W. Width here is 0.10-0.20 in.

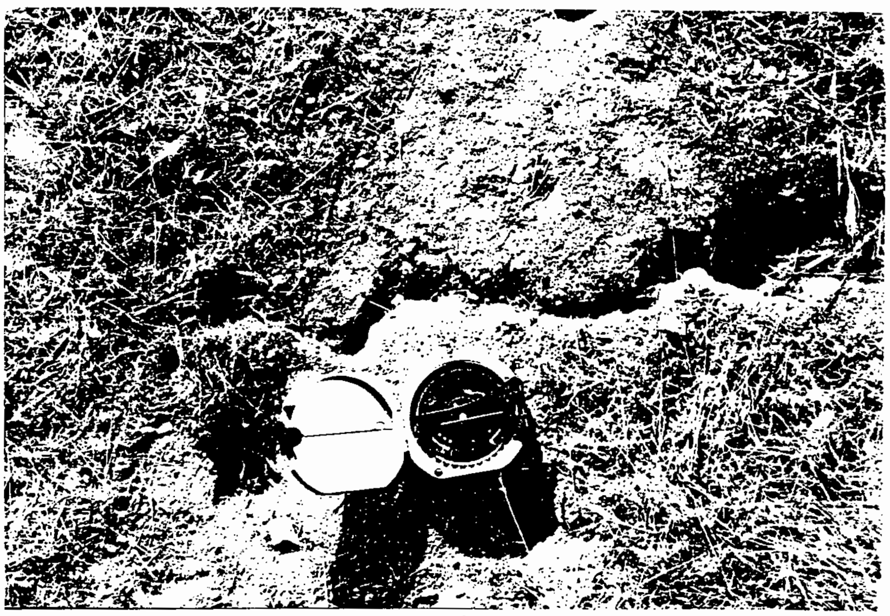

Figure 10. Location 10: Another unusual fracture located about 120 ft east of main breakout depressions. Older fracture terminates in burrow.

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DIVISION OF OIL & GAS
BAKERSFIELD

MEMORANDUM

Elk Hills, CA
December 15, 1993

To: RESMARC

From: RESMARC Subcommittee - Tulare

Subject: RESMARC Subcommittee Meeting Minutes
Meeting Date: December 7, 1993

The Tulare RESMARC Subcommittee sat in session on the above date for the purpose of discussing the agenda items listed below:

Leader	Subject
1. Milliken/Deutsch	Subcommittee Goals
2. Deutsch	Preview of 27WD-7G
3. Milliken	Surface fracturing associated with surface breakouts, 7G/18G
4. Waldron	Case histories and remediation success in other fields
5. Alexander	Feasibility of horizontal disposal and source wells
6. Milliken	Meeting summary and agenda for next meeting

The following staff sat in attendance

DOE	CUSA	BPOI	OTHER
Milliken	Alexander	Sargent	Fries (RMCI)
McLemore	Waldron	Mele	
Harris		Katragadda	
		Deutsch	

RECOMMENDATIONS

1. The work in the action items should be performed as listed.

ACTION ITEMS

A. Milliken and Deutsch will look in to developing a Mission Statement.

B. At the request of Alexander, Katragadda will obtain historical capital and remedial costs back eight years for the source and disposal well programs.

C. At the request of Alexander, Sargent and Katragadda will look into further testing of 18WD-8G and 78WD-7G to see if they can be economically salvaged (the fiberglass liners may be a problem). Sargent and Alexander will check with their respective drilling departments on the feasibility of converting these wells to horizontal disposal wells. Options for horizontal source wells will also be examined as time permits. Deutsch will examine the well logs to see if a tight formation might be the cause of the wells' poor performance.

D. Katragadda will obtain historical pressure and rate charts for 58WD-7G for Milliken. Milliken will analyze the data to identify anomalies that may shed light on surface breakouts. Milliken will also work with Mike Stratton to analyze sequences of events surrounding the breakouts.

E. Waldron will make copies of Chevron's Kern River water disposal program planning documents, one copy each to DOE, BPOI, and CUSA engineering.

<u>DISCUSSION</u> (by agenda item):

1. **Subcommittee goals.** The subcommittee agreed that a mission statement is necessary.

2. **Preview of well 27WD-7G.** Harvey Deutsch presented a review of the criteria used to locate the well. These criteria included avoidance of surface linear features that may be joints.

3. **Surface fracturing associated with surface breakouts, 7G/18G.** Milliken discussed the results of his ongoing attempt to characterize surface fracturing that occurs coincident with surface breakouts. With 35mm slides and transparencies, he gave the subcommittee some idea of the nature and possible causes of surface breakouts and their association with surface fracturing. Attached to these minutes are Exhibits 1, 2, 3, and 4 that present data regarding fracturing and flow to the surface.

Exhibit 1 is a topographic map of the 7G/18G disposal area showing locations and dates of breakouts. The trend is for breakouts and associated fracture zones to occur along NE-trending radials from the responsible wells. The breakouts, generally occurring as point sources, are aligned along a linear NW trend. Milliken interprets the point sources to occur at the intersections of two natural fracture systems that have been reactivated by injection pressures.

Exhibit 2 is a copy of the rate-pressure test for well 58WD-7G conducted in 1991. Tubing fracture pressure was 251 psi. Well 58WD-7G is the latest well to surface, having done so on October 23, 1993. Nominal tubing pressure/rates were 125 psi/25,000 B/D prior to 10/23. It was during this time that fracturing to the surface gradually occurred, culminating in flow to the surface. Fracturing occurred at pressures far less than the 251 psi frac pressure obtained in the test. Milliken feels that fractures induced during the 1991 test probably laid the foundation for shallower fracturing in zones of lower overburden pressure. The pressure and rate for 58WD-7G was increased on 10/23/93 after the spill was recognized and inadvertently attributed to well 38WD-7G. Milliken feels that a secondary breakout occurred during this spike. Since 10/23/93, pressures and rates have been greatly reduced to avoid further water to the surface, but standing water and seeping gas at the secondary breakout still occur. Well 58WD-7G may never be able to inject at rates much above 15,000 B/D without flowing to the surface, unless the fractures are allowed to close and heal themselves with time.

Exhibit 3 is a copy of the chart for well 58WD-7G during the week of October 23, 1993. Fracturing of the surface occurred over a long period prior to Oct. 23, during which time the injection rates were a nominal 25,000 B/D. Flow to the surface occurred prior to the kick to 27,874 at 6:30 PM on Oct. 23. Surface flow was enhanced by the kick, and continued from two adjacent point sources until 6 PM on Sunday, Oct. 24.

Exhibit 4 shows flow rates and tubing pressure data for well 58WD-7G for the periods before and after Oct. 23. Associated charts show injectivity (B/D per psi) and flow rates for the period. Injectivity increased markedly after the Oct. 23 breakout, suggesting the fractures may have allowed injected water access to stratigraphically higher gravels. Standing water in the breakout depression occurs at an injection rate of 15,000 B/D. When the rate is reduced, the standing water disappears.

4. Case histories and remediation success in other fields. Waldron discussed Chevron's success in their water disposal program at Kern River. He mentioned the similarities in well spacing between that project and the our 7G/18G disposal area. At Kern River, high injection rates from closely spaced wells resulted in mounding of water and subsequent fracturing. Disposed water flowed up the fractures to stratigraphically higher oil-producing zones, increasing water cut. In order to maintain disposal capacity, Chevron formed a team of geologists and engineers who drafted formal disposed water management plans. Waldron offered copies of these plans to DOE, BPOI, and Chevron engineering at Elk Hills.

5. Feasibility of horizontal disposal and source wells. Alexander discussed the possibility of using shut-in vertical wells for horizontal wells. Horizontal disposal wells, if technically feasible, would increase our disposal capacity and reduce the need for more vertical wells. Fewer wells would mean lower facility costs and fewer permitting problems. Alexander and Sargent will report their findings at the next meeting.

6. Next meeting. The next Tulare Subcommittee meeting will be held in January (date TBA), and every month thereafter.

<u>NEW BUSINESS</u>

None

12/15/93
Mark Milliken, Chair, DOE

Jim Waldron, CUSA

12/15/93
Harvey Deutsch, BPOI

<u>DISTRIBUTION:</u>

Attendees+
Dave Lefler, BPOI

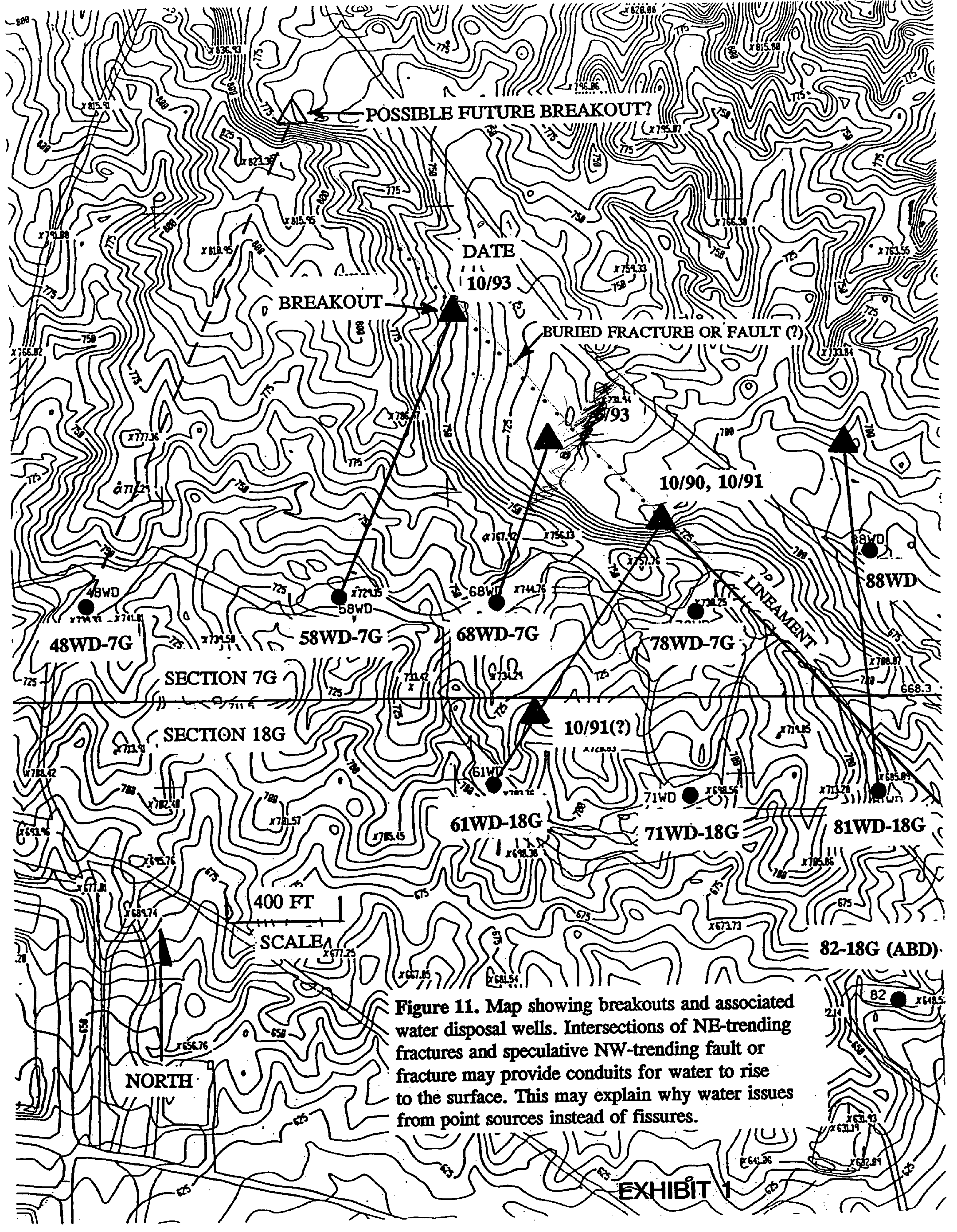


Figure 11. Map showing breakouts and associated water disposal wells. Intersections of NE-trending fractures and speculative NW-trending fault or fracture may provide conduits for water to rise to the surface. This may explain why water issues from point sources instead of fissures.

RATE-PRESSURE TEST
WATER DISPOSAL PROJECT
TULARE ZONE
WELL 58WD-7G

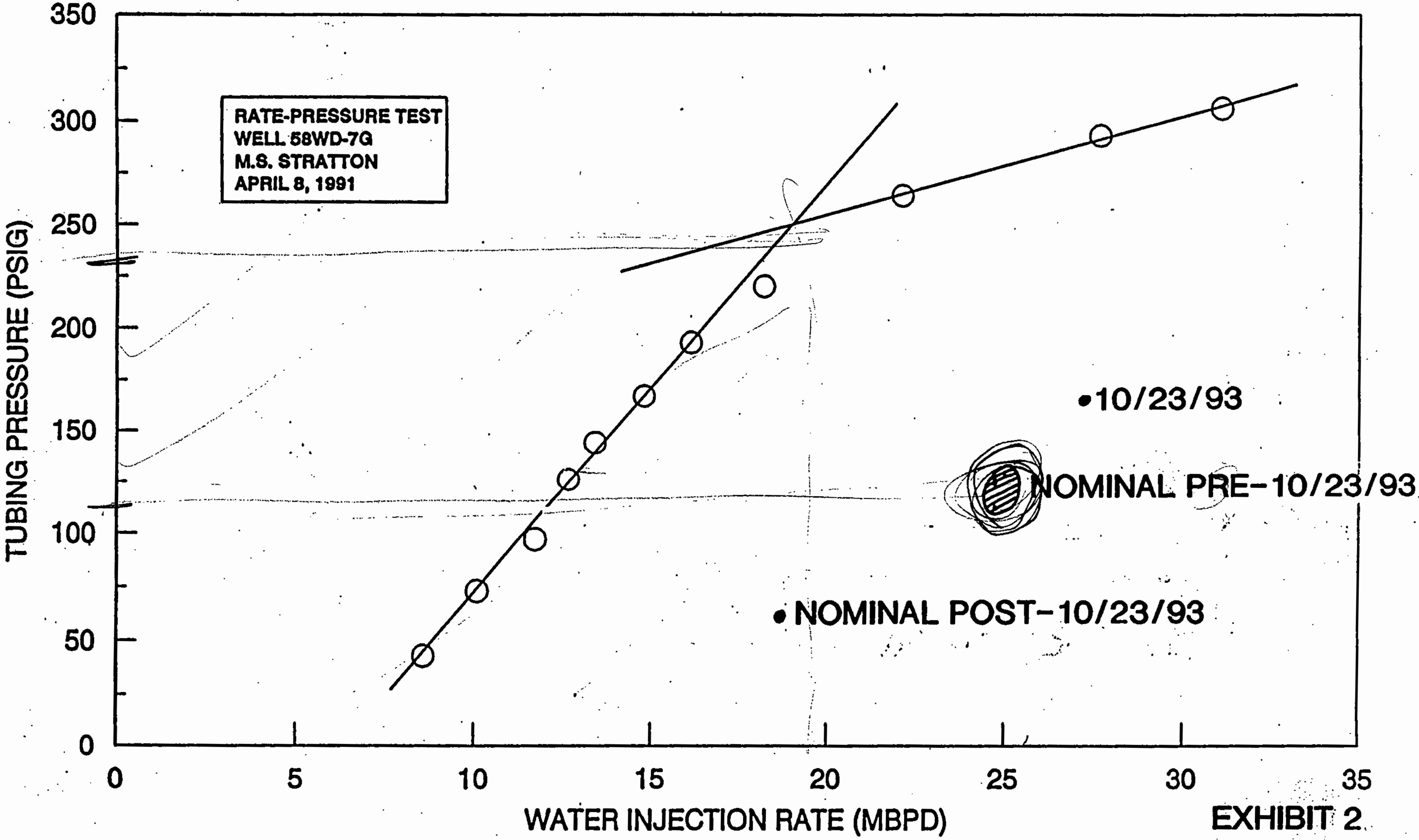


EXHIBIT 2

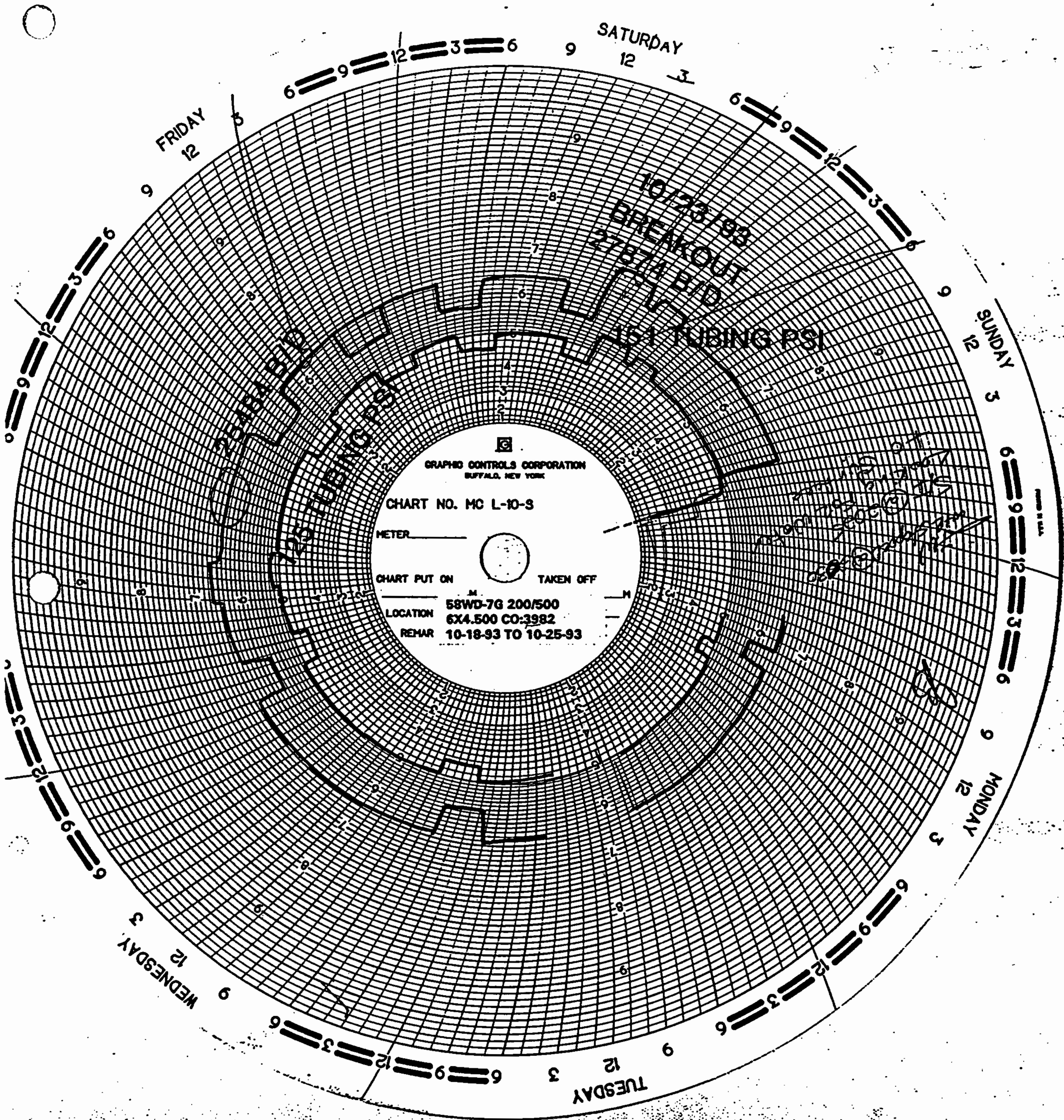
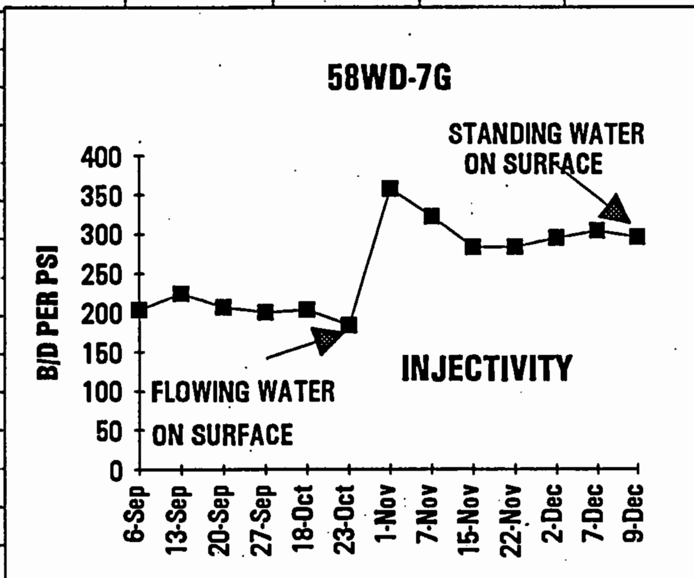

GRAPHIC CONTROLS CORPORATION
BUFFALO, NEW YORK
CHART NO. MC L-10-S
METER
CHART PUT ON
TAKEN OFF
LOCATION
REMAR
58WD-7G 200/500
6X4.500 CO:3982
10-18-93 TO 10-25-93
10/23/93
BREAKOUT
151 TUBING PSI
125 TUBING PSI
SATURDAY
SUNDAY
MONDAY
TUESDAY
WEDNESDAY
FRIDAY

EXHIBIT 3

58WD-7G	TUBING FRAC. PRESS. = 251 PSI,			FRAC. RATE = 19,000 B/D				
DATE	TUBING	RATE	STATIC	DIFF.	%FRAC	%FRAC	B/D	COMMENTS
	PSI	B/D	PEN	PEN	PSI	B/D	PER PSI	
6-Sep	125	25485	5.00	6.40	50%	134%	204	
13-Sep	115	25883	4.80	6.50	46%	136%	225	
20-Sep	125	25883	5.00	6.50	50%	136%	207	
27-Sep	125	25087	5.00	6.30	50%	132%	201	
18-Oct	125	25485	5.00	6.40	50%	134%	204	
23-Oct	151	27874	5.50	7.00	60%	147%	184	FLOWING WATER
1-Nov	51	18317	3.20	4.60	20%	96%	358	
7-Nov	54	17521	3.30	4.40	22%	92%	322	
15-Nov	65	18317	3.60	4.60	26%	96%	283	
22-Nov	65	18317	3.60	4.60	26%	96%	283	
2-Dec	65	19114	3.60	4.80	26%	101%	295	
7-Dec	51	15530	3.20	3.90	20%	82%	303	
9-Dec	51	15132	3.20	3.80	20%	80%	296	STANDING WATER



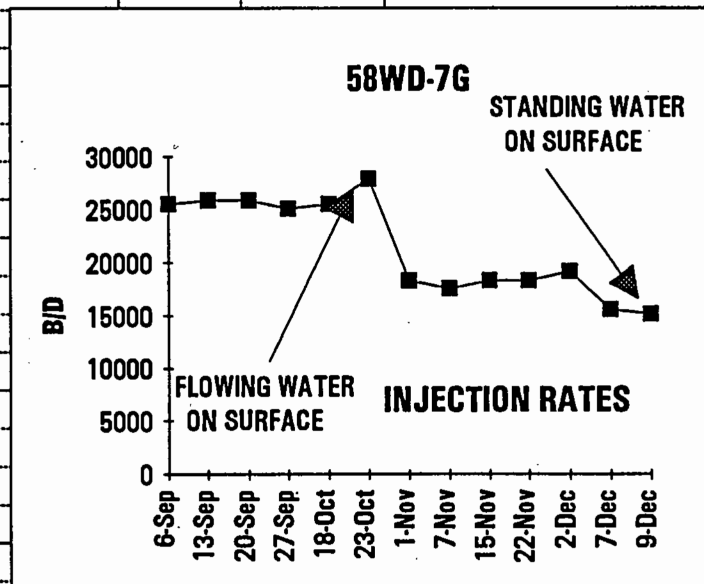


EXHIBIT 4